EVALUATING TXDOT'S SAFETY IMPROVEMENT INDEX – A PRIORITIZATION TOOL

A Thesis

by

GIRIDHAR REDDY SINGI REDDY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Civil Engineering

EVALUATING TXDOT'S SAFETY IMPROVEMENT INDEX
– A PRIORITIZATION TOOL

A Thesis

by

GIRIDHAR REDDY SINGI REDDY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Dominique Lord
Committee Members,	Yunlong Zhang
	Tom Wehrly
Head of Department,	David Rosowsky

December 2007

Major Subject: Civil Engineering

ABSTRACT

Evaluating TxDOT's Safety Improvement Index – A Prioritization Tool.
(December 2007)
Giridhar Reddy Singi Reddy, B.E., Osmania University, India
Chair of Advisory Committee: Dr. Dominique Lord

In accordance with the federally mandated Highway Safety Improvement Program (HSIP), every state is required to "develop and implement, on a continuous basis, a highway safety improvement program which has the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on all highways" (FHWA, 1979). The federal government via the HSIP provides a significant amount of funding that allows every state to improve the safety of their highway network.

With such large amounts of federal funds involved, it becomes essential that state transportation agencies take appropriate measures to utilize these funds in the most cost effective manner. As part of this program, the Texas Department of Transportation (TxDOT) uses a formula known as the "Safety Improvement Index" (SII) for identification, ranking and selection of eligible projects. The SII is in essence used to rank potential projects by giving priority to projects that have a higher benefit-cost (B/C) ratio. Since the SII has not been updated within the last two decades, there is a need to determine whether the current formulation needs to be revised or updated. This concern has been reported in the literature.

The objective of this thesis is to evaluate the SII in its current functional form and its usefulness to rank and prioritize projects for safety improvement. The evaluation procedure proposed in this thesis uses sensitivity analyses to study the effects of different input variables on the SII. The sensitivity analysis is performed with respect to five critical variables chosen on the basis of a literature review. The five variables studied are the Interest Rate, Removal of PDO Crashes, Crash Reduction Factors, Crash Rates, and

Crash – Flow Relationship. The focus of the evaluation is to compare the ranking of projects with respect to changes in the value of these input variables. The ranking are evaluated using various statistical methods, such as the Spearman Rank Order Correlation Test and Kendall's Tau Test.

The results of the analysis indicated that, although changes in the value of input variables affect the SII output, the ranking of projects is usually not affected, with the exception of the crash reduction factor variable. Hence, the same projects will be selected for safety improvement, even if different values are used in the SII. Therefore, it is recommended that the current formulation of the SII and the value of input variables used in the formula be retained by TxDOT for prioritizing safety improvement projects. However, it is suggested to examine the accuracy and uncertainty associated with reduction factors, since in some cases they were found to affect the ranking of projects.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I thank my committee chair, Dr. Dominique Lord, and my other committee members Dr. Yunlong Zhang, and Dr. Tom Wehrly, for their continuous support and guidance throughout the course of this thesis. I specially thank Dr. John Mounce for providing me with the opportunity to work on this project. And I would also like to thank Mr. Danny Morris for providing help with solving number of problems encountered in the course of this thesis.

I thank all my friends, colleagues and other faculty members in the Zachry Department of Civil Engineering at the Texas A&M University for providing support and also making my term here a memorable and enriching one. I also thank the Texas Transportation Institute for providing me with the necessary facilities and resources for my research.

I finally thank my parents and siblings for their unconditional love, encouragement and support they provided me throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In accordance with the federally mandated Highway Safety Improvement Program (HSIP), every state is required to "develop and implement, on a continuous basis, a highway safety improvement program which has the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on all highways" (FHWA, 1979). The federal government via the HSIP provides a significant amount of funding that allows every state to improve the safety of their highway network. The federal program generally funds about 90 percent of the project requirements while state and local agencies are required to fund the remaining 10 percent of the projects that have been selected for safety improvements. With such large amount of federal funds involved, it becomes essential that state transportation agencies take appropriate measures to utilize these funds in the most cost effective manner. As part of this program, the Texas Department of Transportation (TxDOT) uses a formula known as the "Safety Improvement Index" (SII) for identification, ranking and selection of eligible projects. The SII is in essence used to rank potential projects by giving priority to projects that have a higher benefit-cost (B/C) ratio. The formula documented in the index determines the ratio between the expected benefits in crash reduction following the proposed improvements and the costs associated with putting the project into execution, as well as operating and maintaining the project over its design life. The formula in its current form also contains terms related to exposure (i.e., traffic flow), life of the project, interest rates, crash costs and crash reduction factors (CRFs).

This thesis follows the style of Accident Analysis and Prevention.

A recent study documenting different methodologies used by state DOT's to identify and prioritize high risk locations for their HSIP found that most programs contained important deficiencies (Hallmark and Basavaraju, 2002). For instance, many methodologies used by DOTs do not employ any sensitivity analyses or performance evaluation for studying the effectiveness of using different weighting methods and combinations of different factors. The same limitations apply to the SII. In addition, the formula adopted by TxDOT for the SII, first established in 1974, was last revised in 1984 (Mounce, 2005). Given the significant changes in highway safety research that occurred within the past two decades and the necessity to stay in accordance with the HSIP, there is a need to determine weather the equation should still be used in its current form to rank and prioritize projects for safety improvement.

1.1 Study Objectives

The purpose of this thesis is to evaluate the SII in its current functional form, retaining the original values of the variables, and usefulness to rank and prioritize projects for safety improvement. The evaluation procedure proposed in this thesis uses sensitivity analyses to study the effect of different variables on the SII equation output. The focus of the evaluation of the index is to compare the ranking of projects with respect to changes in the values of certain critical variables. Also various statistical methods are used to evaluate the ranking. The specific objectives of the thesis can be stated as follows:

- Perform a review of available literature, published and unpublished, related to HSIP across the United States.
- Identify potential issues with the current formulation.
- Assemble data obtained from TxDOT for analysis.
- Replicate the original SII values for the projects by utilizing all the required inputs.
- Perform sensitivity analyses of the ranking with respect to selected variables.

- Compare modified rankings to the original rankings by utilizing relevant statistical methods.
- Present any significant findings and conduct further research into the specific area.
- Propose relevant recommendations for improving the formula, if needed.

1.2 Thesis Outline

The thesis is divided into six chapters. Chapter II provides a comprehensive literature review on the subject. Chapter III presents details about the data used for the analysis, with procurement and set up discussed additionally in this chapter. Chapter IV documents the data analysis carried out in this research. This is followed by Chapter V, which documents the statistical interpretation and inferences. Chapter VI summarizes the work performed in this thesis and provides recommendations for further research.

CHAPTER II

LITERATURE REVIEW

This chapter documents a literature review performed about the HSIP across the United States. The first section presents the characteristics of the HSIP program used by TxDOT. The second section covers known programs used by other state transportation agencies. The third section describes known issues that have been identified about the SII index and CRFs. The fourth section briefly presents some new procedures proposed as alternative methods for improving the HSIP.

2.1 Hazard Elimination Program (HES) in Texas

This section describes the characteristics of the HSIP used by TxDOT. The HSIP implemented in Texas is known as the Hazard Elimination Program (HES). The legislation regarding the HES program can be found in the Code of Federal Regulation, Title 23, Section 924.5 (Hofener et al., 2003). As described above, 90% of project costs for this program are covered through federal funds and the remaining costs are paid for by the state and local agencies. As per the regulation, the funds provided by the HES program can be used only for safety improvement projects. Figure 1 details the key components of the HES program in Texas.

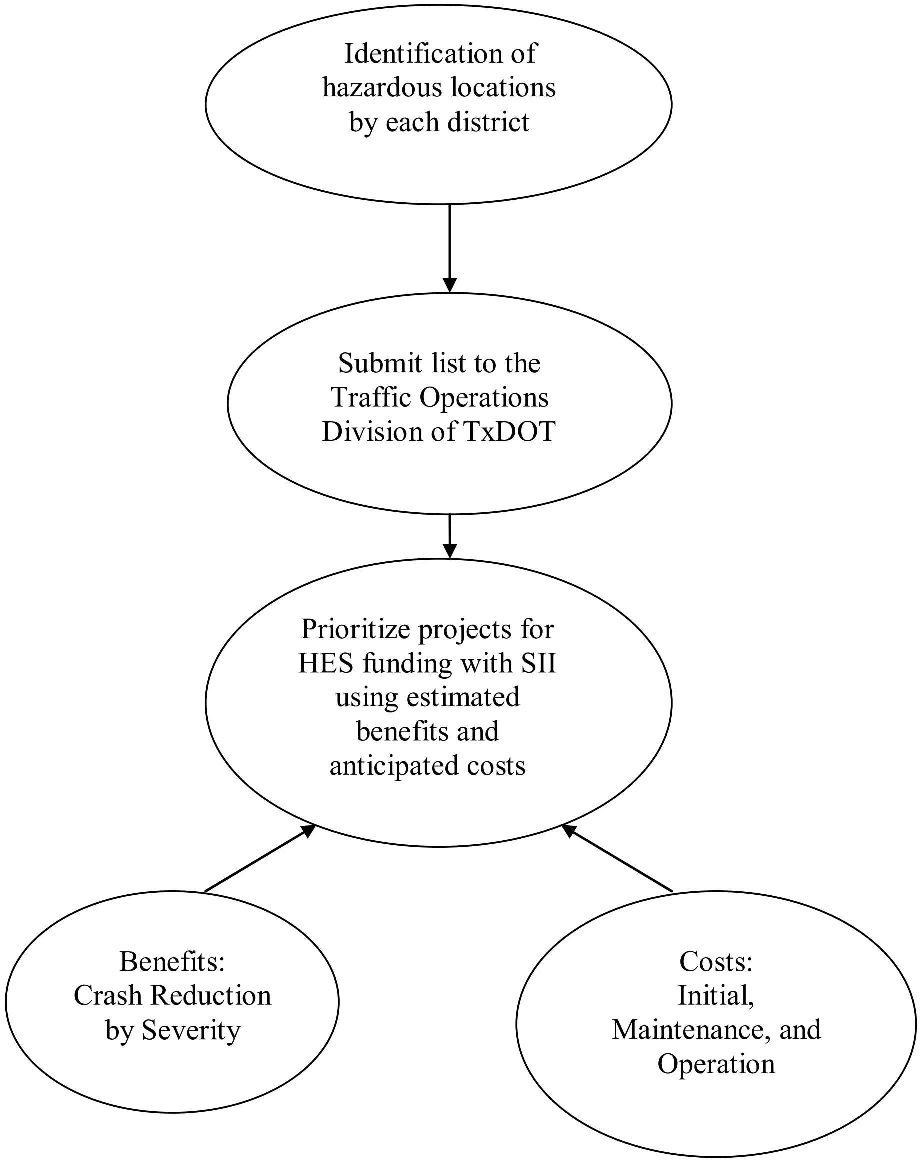

Figure 1. Overview of HES Program in Texas

Figure 1 shows that each TxDOT District sends a list of sites that have been identified has having safety problems as well as the proposed project characteristics to improve the safety of these sites. Each District is responsible for identifying sites characterized with safety problems. Once each District sends its list to the Traffic Operations Division, the office compiles all the projects and ranks each project using the

SII index. The projects are individually funded starting with the most important project and sequentially down until the states allotment of funds is depleted. The details about the index are described below.

As described above, the SII has been an important tool for TxDOT for implementing the HSIP program since 1974 (Mounce, 2005). The equations used for calculating the SII are as follows:

$$S = \frac{R\left(C_f F + C_i I + C_p P\right)}{Y} - M \,, \qquad Q = \left(\frac{\frac{A_a - A_b}{A_b}}{L} \right) S$$

$$B = \frac{S + 1/2Q}{1.08} + \sum_{i=2}^{L} \left[\frac{\left(S + 1/2Q\right) + \left(i-1\right)Q}{\left(1.08\right)^i} \right],$$

$$SII = \frac{B}{C},$$

Where:

B = Present worth of Project Benefits over service life

C = Initial Cost of Project

L = Project service life

S = Annual savings in crash costs (equal to accident cost savings per year less annual maintenance costs)

R = Percentage reduction factor (in this case the CRFs)

F = Number of fatal and/or incapacitating injury crashes

C_f = Cost of fatal and/or incapacitating injury crashes

I = Number of non-incapacitating and/or possible injury crashes

Ci = Cost of non-incapacitating and/or possible injury crashes

P = Number of property-damage-only (PDO) crashes

Cp = Cost of PDO crashes

Y = Number of years of crash data

M = Change in annual maintenance costs for the proposed project relative to the existing situation

Q = Annual change in crash cost savings

A_a = Projected average annual ADT at the end of the project service life

A_b = Average annual ADT during the year before the project is implemented

As one can see, the SII is a B/C formula and hence a project with its SII value greater than 1.0 is considered to be cost effective.

2.2 SII Index Used by Other States

This section documents similar methodologies used by different states to rank and fund projects under the HSIP. It describes the characteristics of the equations used for SII index and documents any possible issues associated with them. The section is divided into two parts. The first part contains reviewed documents that provided detailed information about the equations used for the SII index. The second part describes studies that provided less detailed information (without referring to equations) about the index.

2.2.1 Equation-Based SII Index

Most of the SII indexes used by different states are based on B/C analyses. A recent study conducted by Shen et al. (2003; 2005) on behalf of the Florida Department of Transportation (Florida DOT) documented the different economic analysis methods used by various state DOTs for prioritizing safety improvement projects to obtain federal funding under the HSIP program. The study by Shen et al. put more emphasis on the use of CRFs on the ranking methodology rather than the detailed discussion about the equations used for computing the SII index. A discussion about the characteristics and issues of CRFs are also provided in a subsequent section.

The study by Shen et al. (2005) lists and explains the equations used by the following states: California, Idaho, Virginia, Montana, Indiana, Kentucky, Vermont, Ohio, Arizona, Missouri, and South Carolina. The equations are explained in detail in the next few paragraphs.

Similar to Texas, the states of California and Idaho refer to the B/C ratio as the safety index. The safety index used by Caltrans is calculated as follows (Caltrans, 2005):

$$\text{Initial Accident Rate (IAR)} = \frac{\text{Average no of accidents per year}}{ADT(in1000's) * 0.365 * 7} \tag{1}$$

Expected Accident Rate (EAR) =

$$\frac{\text{Average no of accidents per year} * \text{Accidents reduced.}}{ADT(in1000's) * 0.365 * 7} \tag{2}$$

If EAR ≥ ABR (Accident Base Rate for the project), then use the equation –

$$\frac{B}{C} = \frac{\text{Savings in accident costs} \times 100}{TotalCost} \tag{3}$$

If EAR < ABR, then use the equation –

$$\frac{B}{C} = \left(EAR/ABR\right)^3 \times \frac{\text{Savings in accident costs} \times 100}{TotalCost} \tag{4}$$

The Total cost is calculated using the Preliminary Engineering costs (Environmental and PS&E), Right of Way costs (Engineering and acquisition), Construction costs (Construction and Construction Engineering), and Contingency amount (about 10%).

The state of Virginia for prioritizing its safety improvement projects uses the following formula for calculating the B/C ratio (Shen et al, 2005):

$$\frac{B}{C} = \frac{\sum((((NF \times PRF) + (NI \times PRI)) \times QDollars) + (NPD \times AAPD \times PRPD))_{improvement} \times ATGR}{\left(PECost + R/W \ \& \ UtilCost + ConstCost\right) \times K} \tag{5}$$

Where,

NF = Number of related fatal crashes per year,

PRF = Percentage reduction in fatal crashes,

NI = Number of related injury crashes per year,

PRI = Percent reduction in injury crashes,

QDollars = Weighted average cost of fatal and injury crashes at all similar locations,

NPD = Number of related property-damage-only crashes per year,

AAPD = Annual average cost of property-damage-only crashes,

PRPD = percent reduction in property-damage-only crashes,

ATGR = Projected district annual traffic growth rate,

$\sum(\ldots)_{improvement}$ = Sum of the estimated reduction in crash costs due to each improvement,

PECost = Estimated preliminary engineering costs,

R/W & UtilCost = Estimated right-of-way and utilities cost,

ConstCost = Estimated construction costs, and

K = Capital recovery factor = $\dfrac{i(1+i)^n}{(1+i)^n-1}$ where i = interest rate and n = average service life (year).

It should be noted that the equation above does not include traffic flow as a measure of exposure. Thus, projects located on highways having very different traffic flow exposure could theoretically be assigned the same ranking, if all other variables remained the same between both sites.

The State of Montana uses the following equations to calculate the B/C ratio for its Hazard Elimination Safety Projects (Shen et al., 2005):

$$\frac{B}{C}=\frac{\left[\dfrac{ADT_a}{ADT_b}\right]\times\left[Q(A_{fi})P_{fi}+C_{pd}(A_{pd})P_{pd}\right]}{[C(K)]+M} \qquad (6)$$

Where,

ADT_a = Projected average daily traffic after improvement,

= 1.03L +1 where L = life of the project (years).

ADT_b = Average daily traffic before improvement,

= 1.03-s +1 where S = number of years of crash record used in the analysis,

A_{fi} = Average number of annual fatalities or injuries combined,

P_{fi} = Expected percent reduction in fatalities or injuries,

A_{pd} = Average annual property-damage-only crashes,

C_{pd} = Cost per property-damage-only crashes,

P_{pd} = Expected percent reduction in property-damage-only crashes,

C = Capital Costs,

K = Capital recovery factor = interest rate,

M = Change in annual maintenance or operations costs, and

Q = Average cost per fatal and injury combined,

The value of Q is obtained by using the equation –

$$Q = \frac{Cost\,of\ \ fatal\,crash(F + II) + Cost\,of\ \ Injury\,crash(NI + PI)}{Number\,of\,(Fatal\,Crashes + Injury\,Crashes)}$$

Where,

F = Number of fatal injuries,

II = Number of incapacitated injuries,

NI = Number of non-incapacitating injuries, and

PI = Number of Possible Injuries.

The State of Indiana uses the following set of equations to calculate the B/C ratio for its safety improvement projects (Shen et al., 2005):

First, the benefits are estimated by estimating the reduction in crashes:

Crash reduction benefits (CRB) = CR $\times$ Crash Costs. (7)

Where,

$$CR = N_a \times CRF \times CPF. \tag{8}$$

In the equation above, the various components are given by the following:

CR = Crash Reduction by year of service life,

N_a = Number of crashes (from crash data),

CRF = Crash Reduction Factor, and

CPF = Crash projection factor; it is used to project the number of crashes in a given year. This factor is assumed to be equal to the factor used to project the increase in ADT.

The Crash reduction benefits calculated above need to be adjusted for the present worth, such as:

Adjusted Reduction Benefits (B_{adjust}) = PWF $\times$ CRB (9)

Where, PWF = present worth factor.

Then, the B/C is calculated using the following equation:

$$\frac{B}{C} = \frac{K \times B_{adjust}}{K\left[I_c + \left(M_{ac} \times PWF_{Eps}\right) - T \times PWF_{SP}\right]} \tag{10}$$

Where,

K = Capital recovery factor for the last year of the improvements service life,

B_{adjust} = Summation of yearly adjusted benefits,

I_c = Initial cost,

M_{ac} = Annual maintenance cost,

PWF_{EPS} = Present worth factor (equal payment series),

PWF_{SP} = present worth factor (single payment), and

T = Terminal value.

As previously noted, this equation does not incorporate traffic flow as a measure of exposure. Another interesting observation is that the capital recovery factor 'K' is present in both the numerator and denominator; it is unclear if this caused by a typo or the equation is simply erroneous. Further enquires might be made and a revised equation may be provided in an updated version of this report.

The State of Kentucky uses a dynamic programming (DP) method to select the optimal combination of safety improvement projects. The inputs for the program are the present worth values of benefits and costs. These values are calculated using the following equations (Shen et al., 2005):

$$C = S + \frac{A\left[(1+i)^{L} - 1\right]}{i(1-i)^{L}} \tag{11}$$

$$B = \left[\frac{\frac{(1+t)^{(L+1)}}{(1+i)} - 1}{\frac{(1+t)}{(1+i)} - 1} - 1 \right] \times \frac{\sum_{m=1}^{j} \sum_{n=1}^{3} R_m N_{mn} P_n}{T} \tag{12}$$

Where,

C = Present worth cost of improvement,

S = Construction cost,

A = Yearly maintenance cost,

i = Present interest rate,

L = Life of improvement,

B = Present worth benefit,

t = Exponential growth rate factor for traffic volume,

T = Time (years) of crash history,

J = Number of crash causes associated with the location,

R_m = Percent reduction of m^{th} cause affected by the improvement,

N_{mn} = Number of crashes associated with m^{th} cause, and

P_n = Average cost of a crash (n = 1 = fatality; n = 2 = non-fatal injury; n = 3 = property-damage-only).

The State of Alaska incorporates crash severity as part of the B/C ratio calculation. The state uses crash cost reduction factors instead of CRFs based solely on crash counts. It is to be noted that crash cost reduction factors can be applied only to those crashes which are susceptible to be corrected by the proposed safety improvement. It does not apply to all crashes. The B/C value is calculated using the following equation (Shen et al., 2005):

$$\frac{B}{C} = \frac{CR + M_d}{C_c + M_i} \tag{13}$$

Where,

CR = Estimated annual reduction in crash cost,

M_d = Decrease in annual maintenance cost,

M_i = Increase in annual maintenance cost, and

C_c = Annualized construction cost.

As explained above, the two equations described do not incorporate traffic flow to account for changes in exposure.

2.2.2 General Description of the SII Index

This section describes the general concepts used by some states for prioritizing their projects under the HSIP program. In this section, the equations describing the indexes were not available in the reviewed document. Thus, the discussion focuses on the general methodology for ranking and prioritizing safety-related projects.

The State of Arizona uses an incremental B/C analyses instead of the normal B/C ratio. This method assumes that the relative merit of the safety project is measured by the change in its benefits and costs when compared to the next low cost alternative. This approach is an iterative process resulting in the selection of the most beneficial project out of all the proposed projects. The incremental B/C method is conducted as follows (Shen et al., 2005):

1. Determine the costs and benefits, and the resulting B/C ratio for each individual countermeasure.
2. In the order of increasing cost, list all the projects with a B/C ratio value greater than 1.0.
3. Calculate the incremental B/C ratio of the second lowest cost countermeasure compared to the lowest cost countermeasure. Pick the former if the ratio is positive, else pick the later.
4. Continue in order of increasing costs to calculate the incremental B/C ratio for each countermeasure compared to the last selected countermeasure.
5. Stop the iterative process when the incremental B/C value becomes less than 1.0 (disregarding the negative ratios).

Other states have employed different variations of the B/C calculations described above for ranking and prioritizing projects. For instance, the State of Vermont uses a cost effectiveness ratio (C/E) to supplement the B/C ratio and thus prioritize projects more effectively (Shen et al, 2003a). The State of Ohio employs a rate of return method to calculate an interest rate for the safety countermeasure at which the difference between the net present value of the project and the current estimated cost becomes equal to zero (Shen et al, 2003a). The State of South Carolina uses the net benefit method to compare and rank its safety improvement projects. The net benefits, which is the mathematical difference between the annual costs and the benefits, is used for comparing different projects and hence selecting the best one out of the projects being evaluated rather than the ratio (Shen et al., 2005).

Another study documenting the different economic analysis methods used by different states was conducted by Hallmark and Basavaraju (2002) of the Centre for Transportation Research and Education (CTRE) at Iowa State University. The study identified common identification and ranking techniques used by different states. The main objective of the study was to evaluate the current Iowa DOT's economic analysis. Hence, it provided a section describing the procedure used by the DOT for ranking projects. It then documented a comparative analysis with the other states. Finally, the study presented a significance test for comparing the predicted values with the original estimates as calculated by the Iowa DOT. The test indicated that the study produced a list of safety improvement locations that are statistically significant than the original list of safety improvement locations.

2.2.3 Some Critical Variables from Other States

Brief listing of variables used by other states which essentially are not part of the SII are listed in this section. A comparison to all other states mentioned in the sections above is not provided as it only with few states that the comparison was quite eminent.

Virginia State –

Annual Traffic Growth Rate and the break down of Initial costs into PE costs, R/W costs and Construction costs is not seen in SII.

Montana –

A percentage reduction in different types of crashes is used here where as in SII the number of crashes is used directly. Also a capitol recovery factor K is used in these equations which are not present in the SII.

2.3 Identification of Hazardous Locations

Identification of sites that could be funded under the HSIP has been an important topic in the traffic safety community. This identification process is a vital step within the overall HSIP, since it is essential that the selected engineering countermeasures should lead to a cost effective project (i.e., large reduction in motor vehicle crashes should be observed). Transportation safety analysts have extensively examined and studied different methods for identifying high hazardous locations. This section of the chapter documents the current and on going research on the identification of these locations. It contains a description about the advantages and disadvantages associated with each methodology. The most common methodologies are described below:

1. *Crash Frequency Method* – This method employs the observed number of crashes by location for a given study period. Its advantage lies in its ease of use and also in its simple data requirements. Locations are ranked in descending order and sites with a crash frequency greater than a predetermined number are classified as high-crash locations. For instance, the MUTCD states that locations experiencing more than 5 crashes per year for the last three years should be treated for safety problems (MUTCD 2003). The method's disadvantage is related to not including exposure to capture variations in traffic flow volumes and hence can usually show some bias towards high traffic volume locations (Traffic Institute, 1999; NCHRP, 1986; NCHRP 2000; SEMCOG, 1997; RSM 2003).

2. *Crash Density Method* – This method uses the number of crashes per mile as a measure of identification. Similar to the above method, sites are ranked in descending order and sites with crash density greater than a predetermined number are classified as high-crash locations. The methods advantage is its simplicity, but shows a disadvantage by lacking information about crash exposure (Traffic Institute, 1999; NCHRP, 1986; NCHRP 2000; SEMCOG, 1997; Ogden, 1996).

3. *Crash Rate Method* – This method employs different approaches for segments and intersections. The method accounts for the disadvantage in the crash frequency method as it incorporates both exposure and number of crashes. For links, the method uses the number of observed crashes, traffic volume, and the length of the segment; and for intersections it utilizes a ratio between number of crashes and traffic volume entering the intersections, note that different approaches can be used to compute the exposure based on entering flows. This method avoids a bias towards high volume roadways. However, it tends to select low volume roadways. Thus, it may not be cost effective to select low-volume roads for safety treatments (Traffic Institute, 2000; Homburger et al, 1996; Layton, 1996; McMillen, 1999; RSM 2003).

4. *Frequency-Rate Method* – Some transportation safety analysts have argued that by combining the crash frequency method and the crash rate method, the deficiencies associated with each one can be minimized. With this method, locations are first ranked by using the crash frequency approach and then the locations experiencing high crash counts are re-ranked using the crash rate method. Locations are classified as high-crash locations if they exceed the prescribed minimum crash frequency or crash density and a minimum crash rate. (Traffic Institute, 1999; NCHRP, 1986; NCHRP 2000; SEMCOG, 1997; Traffic Institute 2000; Homburger, 1996; McMillen, 1999; Ogden, 1996; RSM, 2003). It should be pointed out that this method assumes a linear relationship between crash and exposure. This assumption has been challenged by transportation safety analysts (see Hauer, 1997).

5. *Rate-Quality-Control Method* – This method makes use of an equation to determine whether the crash rate at a particular location is statistically different than the average crash rate based on other similar locations. The equation is determined as follows:

$$R_C = R_a + K\sqrt{\frac{R_a}{M}} + \frac{1}{2M} \tag{14}$$

Where,

R_C = Critical Crash Rate

R_a = Average crash rate for locations of similar characteristics

M = Millions of vehicle miles (MVM) for links or millions of total daily entering vehicles (MEV) for nodes.

K = Probability constant based on the desired level of significance.

According to this method, if the actual crash rate at a location is greater than the critical crash rate, it is classified as a high crash location. The main disadvantage of this method is, in comparing the locations with similar physical characteristics, the inherent safety problems are masked. In addition, this method assumes that crash data obeys a normal distribution, which has been found to be inadequate (See Lord et al., 2005). Also the method lacks in considering crash severity (Homburger, 1996; Traffic Institute, 2000; Layton, 1996; Hauer, 1996; Barbaresso et al, 1982; McMillen, 1999; RSM 2003).

6. *Crash Severity Method* – This method weights crashes based on crash severities. Fatal and injury crashes are generally weighted more heavily compared to possible or minor injuries and property damage only (PDO) crashes. The disadvantage of this method lies in its likelihood to highly rank locations based on a single fatality or major injury over locations with numerous but less serious crashes. This method is known for showing a bias towards the rural areas, where the speed of the vehicles is higher, hence associated with more severe collisions (Layton, 1999; McMillen, 1999; RSM 2003).

7. *Severity-Rate Method* – This method combines the crash severity and crash rate methods described above to calculate an equivalent property damage only (EPDO) rate for each location. It is considered to be the most meaningful method by most state and local agencies (Stokes, 1996; RSM, 2003). This method still suffers from the linearity assumptions between crashes and traffic flow volumes.

8. *Empirical Bayes Method* – The empirical Bayes (EB) method was initially proposed by Hauer and Persaud (1984) for the identification of high crash locations. The EB method provides a better estimate for the long-term of a given site and controls for the regression-to-the mean bias (RTM). This method ranks the locations based on the predicted number of crashes calculated by the EB procedure. The method is based on the assumptions that:
a. The number of observed crashes at any site follows a Poisson distribution.
b. The mean for a population of systems can be approximated by a gamma distribution.
c. Changes from year to year from different factors are similar for all reference sites.

The method uses two sources of information for estimating the safety of the site:

- Information obtained from sites that have the same characteristics (control group); and,
- Information obtained from the actual site where the EB method is being applied.

As discussed by Hauer (1997), the EB method is estimated using the following equation:

$$\hat{\hat{\mu}}_{it} = (1-\gamma_{it})y_{it} + \gamma_{it}\hat{\mu}_{it} \tag{15}$$

Where,

γ = Weight factor estimated from reference population for given site *i* and year *t*;

y_{it} = Observed number of crashes for given site *i* and year *t*;

$\hat{\mu}_{it}$ = The estimated number of crashes by crash prediction models for given site *i* and year *t* (usually estimated using a NB regression model).

The weight factor γ_{it} is given as follows:

$$\gamma_{it} = 1/(1+\alpha\hat{\mu}_{it}) \tag{16}$$

Where,

α = The dispersion parameter of the NB regression model. (Note: in the safety literature, analysts have also used the inverse dispersion parameter $\phi = 1/\alpha$)

This method is considered the best method to identify hazardous sites. The main disadvantage noted with this one is related to its extensive data requirements (Hauer and Persaud, 1984; Persaud, 1999; McMillen, 1999; RSM 2003).

Hauer et al. (2004) have studied five alternate ranking criteria for selection of cost effective projects from the list of hazardous locations, or as called by Hauer – sites with promise. They identified the criteria as follows:

1) Sites where most accidents are expected;
2) Sites where most severity-weighed accidents are expected;

3) Sites where most excess accidents are expected;

4) Sites where most severity weighted excess accidents are expected; and finally

5) Sites at which the product (accidents/mile-year) * (excess accidents/mile-year in standard deviations) is highest.

The above study used detailed engineering studies (DES) and also Empirical Bayes estimation for comparing the five criteria. After choosing the top priority locations using the five criteria, DES were conducted at these sites and the best criteria identified. The research concluded that the sites with most accidents or most severity-weighed accidents are expected to lead to most cost-effective projects.

Persaud et al. (1999) proposed the use of a modified EB method for identification and ranking of high accident locations. The method computes difference between the EB estimate and the estimate of negative binomial regression model for ranking the locations (note: this has also been referred to as sites with promise by Ezra Hauer). They compared this method with the conventional estimation methods, the normal EB method and found that the proposed provided more efficient results.

Researchers in Belgium evaluated the application a hierarchical Bayesian model for identifying and ranking hazardous sites (Brijs et al., 2004). They found that the model can overcome the problem of random variation in crash counts and performed better than traditional identification models. The hierarchical Bayesian model used a bivariate Poisson modeling framework, which allows for the covariance between variables. A more detailed description of the technique can be found elsewhere (Brijs et al, 2003).

Falcoocchio et al. (1994) conducted a study on ranking problematic intersections in Brooklyn, N.Y., by using crash data and delay measures. The method determined the severity of problems at the study locations and ranked the problematic intersections from the most to the least cost efficient. The method incorporated the magnitude of delay and severity of the crashes, combined with an importance factor, at each intersection to measure its performance.

A study performed by Breyer (2000) for the Arizona Department of Transportation (ADOT), as part of the FHWA-sponsored corridor safety-improvement program for Arizona, demonstrated the application of advanced technologies for highway safety evaluation. He utilized GIS, photo log and global positioning satellite systems to achieve the objectives defined by his research. He reported that the tools were very helpful in identifying the high accident locations effectively (Breyer, 2000).

Tarko et al. (1996), in a study for the Indiana Department of Transportation, proposed the use of a regression model for detecting of sites to be considered for safety treatment. They proposed a negative binomial regression model with the following form:

$$N = \beta_o Y^{\delta} e^{\sum \beta_i X_i} \tag{17}$$

Where,

N = Expected annual number of crashes,

Y = VMT (veh-mi/day),

X_i = Other county characteristics measured on annual basis (explanatory variables), and

δ, β_i = Regression coefficients.

The expected number of crashes, obtained from the regression model, is used as a reference value for comparing the observed number of crashes in the counties. The decision of whether the county is experiencing a safety problem is based on the comparison. Also the authors have proposed the use of a stepwise regression procedure for avoiding model overfit. The stepwise approach includes two phases namely – Forward selection and Backward Elimination. The details of the procedure can be obtained from the study itself.

2.4 Crash Reduction Factors

Crash Reduction Factors (CRFs) are used to estimate the reduction in number of crashes at a location where a safety countermeasure is planned to be implemented. CRFs are used by many jurisdictions to calculate the benefits associated with a project, and hence decide whether to implement the safety improvement or not, as described in Section 2.1. As documented by Shen et al. (2003a), about 80% of state DOTs in the U.S. use some kind of reduction factors to quantify the safety improvements for locations that have been identified as hazardous (Shen et al, 2003a; Lord et al, 2005; Niesser, 2005; Hanley et al, 2000).

The scope of CRFs in this project can be seen in its application in the various B/C equations described above. The SII equation employs CRFs and is usually defined 'RF' or R in the benefits part of the B/C ratios. CRFs are defined as follows (Lord et al., 2005):

$$CRF = 1 - \frac{N_w}{N_{w/o}} \tag{18}$$

Where,

CRF = Crash reduction factor associated with a specific improvement,

N_w = Expected number of crashes with the improvement, crashes/yr, and

$N_{w/o}$ = Expected number of crashes without the improvement, crashes/yr.

Mounce (2005) conducted a study for TxDOT on the evaluation of the HES program and the application of CRFs for calculating the SII index. The study evaluated the reduction in crashes for 440 projects. Statistical tests (Z and Chi-Square) were used to evaluate whether or not the CRFs properly predicted the reduction in motor vehicle crashes, for the treatments grouped by categories. The study concluded with statistical significance that the HES program was effective in decreasing the crash rates. Mounce recommended this type of evaluation be performed on a regular basis in the future.

A study conducted for the Iowa Department of Transportation (IDOT) by Thomas et al. (2001) on the effectiveness of intersection safety improvements evaluated the application of CRFs as a measure of effectiveness. The researchers reported that CRFs applied for the different safety improvement projects were remarkably similar to the ones they calculated using the crash data.

As described above, CRFs are a key component on the economic analyses for ranking sites for safety improvements. Despite their wide application, CRFs have several biases, and are highly dependent upon the methods used for their development. There has been considerable research conducted on these biases. They include among others: site selection bias, crash migration, CRFs for different crash severity and type, single-value CRFs, CRFs for multiple countermeasures (Lord et al., 2005). They are described in greater details in a subsequent section.

2.5 Reported Issues with the SII

As seen from the documents described above, one can point out areas in which the index needs scrutiny. Numerous transportation safety analysts have documented important flaws; others have proposed ways to mitigate or improve the SII index. The following section provides a brief description about the issues that have been identified in the literature.

A study conducted by TTI researchers in 1995 reported a critical analysis of the SII index (Hofener et al., 2003). The outcome of the analysis raised important issues. The key issues are summarized below; the reader is referred to the original report for additional details:

CRFs – The study noted CRFs as one of the most consequential variables in the SII index. The authors expressed their concern with respect to the use of CRFs for different situations, such as: Is a given work code equally effective on reducing crashes under different highway, traffic, and environmental circumstances?; How to use CRFs for project locations undergoing multiple treatments?; Is it reasonable to assume that a given safety improvement is equally effective for all crash severity types?

Crash Costs – It was observed that when calculating crash costs, which vary as significantly as the above point, the SII index shows a bias towards favoring urban projects over rural projects due to the low crash costs associated with urban projects. The authors suggested subdividing crash costs between rural and urban types in the future calculations.

Inflation Rates – The interest rate being used in the SII currently is 8%. This discount rate is observed by many as too high and thus is biased towards projects with shorter service lives over projects with longer service lives. The authors recommended the use of a lower discount rate of around 4% for eliminating this bias.

Allotment Procedure – TxDOT does not allow for two or more proposals per project for consideration under HES funding. The study suggested that this might be of disadvantage to TxDOT as sometimes applying two or more remedial measures to a single site might improve the safety at the location. Application of more remedial measures facilitates the projects funding due to the added benefits the project experiences in the calculation of the SII index.

Calculable Costs – The crash cost data used by SII index are derived from the estimates provided by the National Safety Council (NSC). Hofener at al. (2003) noted that NSC provides two types of costs for analyses purposes, direct costs and comprehensive costs. The NSC states that direct costs should not be used in crash data analysis. Hence, the NSC recommends the use of comprehensive costs for the SII index.

As discussed earlier CRFs play a very vital role in the calculation of the SII index. Hence, issues related to CRFs will affect the manner the SII index is used. There have been many issues reported by transportation analysts with respect to CRFs; some were related to their development procedures while others were associated with their application.

With respect to the development process, most of the state and local transportation agencies have developed CRFs using a simple before-after study, since it is the easiest method available for practitioners (Hauer, 1997). Important issues related to the development of CRFs using simple before-after studies are described as follows (Hauer, 1997; Shen et al., 2003; Shen et al., 2005):

a) *Regression-to-the-mean*: Generally, a site experiencing a high number of crashes at a particular point of time will show a reduction in the observed number of crashes because of its tendency to move towards its long term mean of that given site. When an estimation of the change in safety brought about by a potential treatment implemented at that point of time whilst it showed higher crash values, it is generally expected to observe a reduction in crashes even if the treatment was not implemented. Hence, the outcome of the simple before-after study will overestimate the safety effects of a treatment. This phenomenon has been referred to as the "Regression-to-the-mean" bias. It is also sometimes given the tag of "regression artifact" and is sometimes erroneously referred to as "selection bias" (Lord et al., 2005; Tarko et al., 1998)

b) *Crash migration*: It is generally described as the shift in the pattern of crashes either geographically or non-geographically (like severity level/crash type). Mountain and Fawaz (1992) in their research discussed the potential reasons for crash migration such as – change in driver behavior and 'end effects' in certain types of improvements.

c) *Maturation*: Council et al. (1980) discussed the phenomenon associated with 'maturation.' This phenomenon describes the changes in the number of crashes due to the trends observed in traffic flow, weather and crash reporting practices over time. Hence, not including maturation in before-after studies would sometimes overestimate the change in safety.

It should be pointed out that most of these issues can be mitigated using the EB method. But due to the extensive data requirement of this method, it has not been widely used by state and local transportation agencies (Shen et al, 2003).

With respect to the development and application of CRFs, the issues that have been identified by some researchers are described as follows (Shen et al, 2003; Shen et al., 2005; Lord et al, 2005):

CRFs for multiple countermeasures: Safety improvements are often done in combinations and may be subjected to a certain level of interdependency. For instance, road widening and shoulder widening can take be implemented at the same time and their effects on safety are not independent form each other. Traditionally, CRFs have so far been developed for individual treatments, with the assumption that all other factors to remain unchanged. Therefore, when several treatments are implemented simultaneously, each CRF is applied independently of each other in the SII index. In truth, the assumption that each treatment is independent of each other is not valid or has not been corroborated. There is currently a research project at the national level (NCHRP 17-25) that is currently looking into developing CRFs for combined treatments.

Transferability issues with CRFs: Most state DOTs and other transportation agencies have adopted CRFs from other jurisdictions. It is unreasonable to assume that CRFs developed from one jurisdiction can be applied directly to another without proper calibration, as highway design practices, weather patterns, crash reportability criteria will be different. These differences will affect the magnitude of the reduction factors. TxDOT Project 4703 will address the calibration of CRFs.

CRFs for different crash types and severity levels: One area of concern is related to CRFs that have been developed for the total number of crashes (all severity included) and for all crash types together. As described in the previous issue, it is expected that the implementation of a treatment will not influence different crash severities the same way nor will it affect crash types equally. Hence, there is a need to develop CRFs for different crash severities and crash types. NCHRP 17-25 will provide some CRFs for different crash severity and types.

Migration or spillover effects: As discussed earlier in the section, crash migration is one of the problems associated with development of CRFs. This issue of crash migration should be kept in mind when designing for a CRF, so that an improvement made can account for such affects and thus help prevention of some spillover effects.

These are most of the issues associated with CRFs, but there might be some other issues which have not been looked into so far and have not come to discussion here.

As seen from the literature above, there is a large scope for improvement with respect to the CRFs and indirectly with the SII. Research in this direction has started in hope of finding some solutions.

In summary, this section of the report has shown that the current HSIP used by TxDOT and other different state agencies suffers from important limitations:

1) Many SII indexes do not include changes in exposure between the before and after periods;
2) If they do, they do not account for the non-linear relationship between crashes and exposure;
3) All SII indexes use observed crash counts rather than the long-term mean associated with each site under investigation;
4) CRFs do not take into account the regression-to-the-mean and site selection biases among others. Thus, the estimated reduction is often over-estimated;
5) CRFs are usually developed and applied for different crash severities;

6) In the economic analyses, the discount rate is usually too high and should be more flexible;

7) The HISP does not allow for sensitivity analyses; and,

8) Low cost projects are always ranked higher than high cost projects, even though the safety effects of the treatment associated with the former are often unknown.

2.6 New Procedures to Prioritize Safety Improvement Projects

Some researchers have proposed some new methods for prioritizing safety improvement projects. Two such procedures have been discussed in this section. They have been applied to rank intersections.

2.6.1 Use of Intersection Delay Analysis

Lu (1999) from the University of South Florida has developed a procedure that incorporates vehicle delay at intersections. This author utilized the output of the intersection delay analysis along with the safety performance for prioritizing safety improvement projects. The new model used a utility function combined with a logit regression model. The steps of the proposed procedure are described as follows:

Step 1:

- Determine priority list I based on B/C ratio.

Step 2:

- Determine priority list II based on the average total delay ranking. The average total delay rank is obtained by considering both d_1 and Δd. Δd is equal to the difference between d_1 and d_2, where d_1 is the delay before improvements, and d_2 is the delay after improvements.

Step 3:

- Determine priority list III based on the logit regression model - $p = \frac{e^U}{1+e^U}$

Where U is the utility function, and is determined using the following equation

$$U = a_0 + a_1(B/C) + a_2 d_1 + a_3 \Delta d \quad (19)$$

Where,

U = utility,

B/C = benefit/cost ratio,

d_1 = delay before improvements,

Δd = delay reduction due to improvements, and

a_0, a_1, a_2, and a_3 = coefficients.

The logit regression model was used mainly to combine safety and operational performances to generate a priority list of intersections which need improvements. The intersection with a larger probability (p) gets higher priority for approval.

2.6.2 Road Safety Risk Index

De Leur and Sayed (2002) developed a subjective evaluation technique known as the Road Safety Risk Index (RSRI) to identify and diagnose problematic highway sections. The RSRI employs concepts related to observed traffic conflicts and on-site drive-through safety reviews. The RSRI combines three forms of risk: 1) exposure of road users to road hazards, 2) probability of becoming involved in a collision, and 3) the resulting consequences in the event of a collision. This can be explained in the form of an equation as follows:

Risk = function of (exposure, probability, and consequence)

The RSRI equations formulated by the authors can be described as follows (Leur and Sayed, 2002):

$RSRI_{specific} = E_i \times P_i \times C_i$, used to assess risk associated with each road feature, and

$RSRI_{combined} = \sum_{i=1}^{n} E_i \times P_i \times C_i$, used for overall risk by combining $RSRI_{specific}$ scores for all road features.

Where,

E_i = Risk score due to exposure for road feature i,

P_i = Risk score due to probability for road feature i,

C_i = Risk score due to consequence for road feature i, and

n = Number of road features investigated.

The risk score for exposure is calculated as follows:–

$$Exposure_{urban} = \left(\frac{V_{i(mjr)} \times V_{i(mnr)}}{V_{\max(mjr)} \times V_{\max(mnr)}} \right) \times 3.0 \text{, and}$$

$$Exposure_{rural} = \left(\frac{V_i}{V_{\max}} \right) \times 3.0$$

Where,

$V_{\max(mjr)}$ = Maximum volume on major road,

$V_{\max(mnr)}$ = Maximum volume on minor road,

$V_{\max}$ = Maximum volume on the corridor under review, and

V_i = Volume at the location of a specific road feature.

The probability score is obtained from the guidelines provided by the study on a four point scale, thus providing a probability score for each road feature ranging from 0 to 3.0, with a high score representing a high probability of an accident.

The risk score for consequence is calculated using the equation –

$$Consequence_{rural} = \left(\frac{PS_i}{PS_{\max}} \right) \times 3.0$$

Where,

PS_i = Posted speed at the location of a specific feature, and

$PS_{\max}$ = Maximum posted speed.

The study also evaluated the validity of the RSRI by comparing it with an objective measure of safety defined as the potential for improvement. The potential for improvement is calculated by taking the difference between the existing and estimated crash frequencies. The authors used a spearman rank correlation to determine the level of agreement between the two methods. They reported that the ranking done by these two methods was at a 99% agreement level, thus validating the use of the RSRI.

2.7 Chapter Summary

This chapter presented a review of the literature available on and relevant to the topic of SII from different time frames, jurisdictions and researchers. The chapter first introduced the HES program to the readers and then explained the procedure of running the HES program in the state of Texas using the SII formula. The application of HES program in other states of the United States with the use of similar formulae was also examined. The focus was then shifted to critically studying the SII formula for identifying potential issues related to the ranking process. In this process, some issues related to the SII and also few suggestive measures were described. The next chapter describes the data collection process.

CHAPTER III

DATA COLLECTION AND COMPILATION

This chapter describes how the data used in this thesis were collected and assembled. The sources of data are first described, followed by a summary of the critical variables used in the analysis. Then, the steps used for assembling the data are presented.

3.1 Data Collection

From the Traffic Accident Information & Hazard Elimination Manual of TxDOT (2004), a table containing the sources of different data necessary for calculation of each project's SII is shown below –

Table 1 - Sources of SII Data

Data Item	How it is Obtained
R – Percentage Reduction Factor Note: The reduction factor represents the percentage reduction in accident costs or severity that can be expected as a result of the improvement.	From the HES work Codes Table (contained in Appendix C). Note: If the project is represented by more than one work code, TRF program administrators derive a composite reduction factor.
F – Number of fatal and/or incapacitating injury accidents I – Number of non-incapacitating and/or possible injury accidents P – Number of property-damage-only (PDO) accidents	The master Accident Decoding manual is used to interpret the codes provided by DPS in the HES work Codes Table column of preventable accidents, and thus determine the number of each type of accident (Appendix C).
C_f – Costs of fatal and incapacitating injury accidents C_i – Costs of non-incapacitating and/or possible injury accidents C_p – Costs of property-damage-only (PDO) accidents	The average cost of each type of accident is based on the comprehensive cost figures provided by the National Safety Council. The program call provides the cost figures used each year.
L – Project service life	From the HES Service Lives table (Appendix D). Note: If the project is represented by more than one work code, TRF program administrators base the project service life on the primary work.

Safety Project Records provided by TxDOT were used for this thesis. The dataset used for analysis consisted of 230 projects that were classified as safety improvement projects and were "qualified" to receive HES funding over a span of 9 years – 1990 to 1998. (Note: All other projects from these years which did not qualify to receive HES funding were deleted by TxDOT from their database and hence were unavailable for this research.)

Each safety improvement project submitted to TxDOT for HES funding is defined as a Safety Project Record Dump. The record dump provides a compilation of relevant data to the project such as work codes, 3 yr period of accident history – before and after, ADT values – present and future, Number of crashes – Fatal, Injury and Property-damage-only, Maintenance costs, Total Estimated Costs, and the originally calculated SII value. A sample safety project record dump is shown in Figure 2.

The record dumps were obtained originally for another project by TxDOT which studied the effectiveness of crash reduction factors for the HES program (Mounce, 2005). The data provided were available in electronic form. The record dumps in original are prepared by TxDOT to serve before after studies. The record dumps hence have a lot more additional information related to the projects than reported above, but the variables stated formerly were utilized in this project and hence were emphasized.

A brief overview of the variables included in the record dumps is provided in the Table 2. The table showcases few summary statistics of the variables such as – Mean, Maximum value, Minimum Value, Standard Deviation, and Sum (if applicable). The summary stats are provided for these variables with respect to each program year and also for the whole data set. (Note – The standard deviation for the entire dataset was obtained as a mean of the standard deviations for the 5 program years)

```
SWS.8701                                   SAFETY PROJECT RECORD DUMP                                       03/26/2004

                           SER        -------------------LOCATION-------------------                UPD    UPD    UPD       UPD      UPD
                         TRANS SER                                                       UPD  UPD   CNTL   BEG    END       MP       MPE
  UNIQUE     SER DATE    CODE  LOC HWY ROUTE CONTRL-SEC BEG MP END MP LENGTH FLAG DIST CTY   SEC     MP     MP       DATE     FLAG

1998 02004S  1-31-1996   A      2  01  0067  0079 - 05  01.200 01.200  00.1   N    02  073 0079-05 01.200 01.200  1-31-1996  N
                                   05  0914  0550 - 03  00.000 00.000  00.0   N    02  073 0550-03 00.000 00.000  1-31-1996  N

                    PART
CTY STATE  SVCE  OF         BEFORE  ACC BEFORE AFTER  ACC AFTER    WORK  SAFETY SAFETY SAFETY SAFETY REDUCTION        QUAN  QUAN
NO. FORCES LIFE ROAD FWY     YRS       DATES     YRS     DATES      CODES  CODE1  CODE2  CODE3  CODE4  FACTOR    SII  IMPRV UNITS

 73   N    10.0  1    N      3   011992-121994  3  011999-122001  107     1G                              28       3.22   1.0  X


PROJECT COMMENT        - 1 INCAP. INJ. ACC.; 11 NON-INCAP./POSS. INJ. ACCS.; 5 PDO ACCS.            PSE REVIEW  LETTER OF
PROJECT LIMITS         - INTERSECTION OF US 67 WITH FM 914 IN STEPHENVILLE                              DATE      INFO DATE
PROPOSED IMPROVEMENTS  - INSTALL TRAFFIC SIGNAL
NUMBER OF LANES        -  2

-----------------BEFORE CONSTRUCTION----------------* -----------AFTER CONSTRUCTION-----------    FINAL        FINAL       ANNUAL
  AID          PRES   FUTURE   PROJ       FAT     INJ          AID        AADT       FAT    INJ       ACCEPT       ACCEPT      REPORT
HWY   CLASS  ADT      ADT      ADT    FAT ACC INJ ACC PDO  HWY   CLASS  AFTER  FAT ACC INJ ACC PDO  REQ DATE      DATE        DATE
             (DIVIDED BY 1000)                                         (1000)
 U  R   3  17.400  22.968  28.536  003 001 019 011 005   U  R   3   18.100  000 000 005 003 002
 U  R   4   2.400   3.624   4.848  000 000 000 000 000   U  R   4    3.100  000 000 000 000 000


                 ACCIDENT TOTALS:  003 001 019 011 005                     000 000 005 003 002

   PGM      MIN       MIN                PROJ     DIST    AUSTIN  ACTUAL                         ROW         TOT          TOT
  CNTRL    ORDER     ORDER     ITEM      LET      LET      LET     LET         FEDERAL             EST         EST         MAINT
  DATE      NUM      DATE      NUM       DATE     DATE     DATE    DATE      DESIGNATOR            COST        COST         COST

 7-09-1996  06713  1-25-1996  99999   9-1999  10-1997  10-1997  10-1997   STP 97(605)HES                       80.0         34.0

   LOA          LOA         LOA PE       LOA PE    FINL            % CMPL   PSE EST     STAT CNCL  CONTROL    CSJ LETTING     FINAL
   DATE         AMT          DATE         AMT      CHGS    CSJ       PSE      AMT       CODE CODE    CSJ         COST         COST

                                                     3  0079-05-045                                0079-05-045    93698.58     150014.72



                                                       COST TOTALS:            0.00                               93698.58     150014.72

 OVERRUN NOTIF/RESP DATE   FORM 240 DATE  % COMPL CONST  WORK ORDER DATE   WORK BEGAN DATE   WORK ENDED DATE

                                                  100         11-14-1997        2-26-1998         7-16-1998

FLD CHG NUM  FLD CHG DESC                                  FLD CHG AMT   FLD CHG DATE
```

Figure 2 – Safety Project Record Dump

Table 2 - Summary Statistics

Variable	Year	1998	1996	1995	1994	1992	Total
Service Life	Mean	10.94	17.00	15.49	15.26	12.99	14.34
	Max	20.00	30.00	30.00	25.00	20.00	30.00
	Min	10.00	10.00	10.00	10.00	6.00	6.00
	S.D	2.96	4.78	5.10	4.64	4.54	4.41
	Total	--	--	--	--	--	--
Present ADT (in 1000's)	Mean	14.33	11.53	13.57	11.29	15.36	13.22
	Max	158.72	44.00	173.59	107.00	101.71	173.59
	Min	1.33	0.58	0.56	0.50	0.35	0.35
	S.D	28.56	10.69	26.74	17.23	14.46	19.54
	Total	458.49	461.28	556.20	429.13	1213.31	3118.41
Future ADT (in 1000's)	Mean	20.47	16.99	18.95	15.91	21.04	18.67
	Max	260.30	58.52	228.27	147.13	125.81	260.30
	Min	1.78	0.72	0.96	0.78	0.50	0.50
	S.D	46.34	16.15	35.40	23.58	18.81	28.06
	Total	655.16	679.77	776.93	604.71	1661.91	4378.48
Fatal Crashes - Before	Mean	2.97	2.70	4.17	0.32	0.66	2.16
	Max	20.00	14.00	18.00	3.00	5.00	20.00
	Min	0.00	0.00	0.00	0.00	0.00	0.00
	S.D	3.86	2.61	4.27	0.66	1.01	2.48
	Total	95.00	108.00	171.00	12.00	52.00	438.00
Injury Crashes - Before	Mean	12.03	16.73	16.44	8.68	17.20	14.22
	Max	123.00	180.00	83.00	72.00	149.00	180.00
	Min	0.00	0.00	0.00	1.00	0.00	0.00
	S.D	24.01	31.99	22.21	12.41	21.72	22.47
	Total	385.00	669.00	674.00	330.00	1359.00	3417.00
PDO Crashes - Before	Mean	11.97	20.13	17.66	7.50	23.48	16.15
	Max	134.00	259.00	96.00	65.00	242.00	259.00
	Min	0.00	0.00	1.00	0.00	0.00	0.00
	S.D	24.78	45.20	23.65	11.19	36.74	28.31
	Total	383.00	805.00	724.00	285.00	1855.00	4052.00
CRF	Mean	38.50	45.20	40.83	44.21	38.23	41.39
	Max	60.00	95.00	80.00	95.00	80.00	95.00
	Min	10.00	10.00	20.00	20.00	10.00	10.00
	S.D	13.53	19.00	14.37	20.99	15.73	16.73
	Total	--	--	--	--	--	--
Total Estimated Cost	Mean	120738	359575	354178	223679	235318	258697
	Max	1148700	1974300	2500000	4500000	1835100	4500000
	Min	11000	8000	6000	12200	13500	6000
	S.D	222892	493508	522375	726868	374057	467940
	Total	3863600	14383000	14521300	8499800	18590100	59857800
SII Given	Mean	11.09	8.87	11.65	3.33	4.96	7.98
	Max	39.44	61.07	108.69	34.10	49.92	108.69
	Min	2.11	1.02	1.60	0.26	1.00	0.26
	S.D	8.54	13.12	20.88	5.41	7.50	11.09
	Total	--	--	--	--	--	--

As it can be seen from Table 2, the dataset has an average Service life of 14 years with a standard deviation of 4.41, the Present ADT and Future ADT are on average 13,220 and 18,670 respectively, the average value of CRFs was observed to be 41.39% with a standard deviation of 16.73, and the SII was on an average found to be 7.98.

Crash costs used - by severity levels, were obtained from TxDOT for the relevant years – 1990 to 1994. The crash costs corresponding to the last year of the 3 before years were used for calculating the SII respectively for each project. The Crash Costs which were used for the project are shown in Table 2 as follows - (the crash costs are the same ones as the ones used by TxDOT.

Table 3 - Crash Costs by Program Year

Crash Year	Fatal Crash Cost	Incapacitating Crash Cost	Non-Incap. Crash Cost	Possible Injury Crash Cost	PDO Crash Cost
1994	$200,000	$200,000	$16,500	$16,500	$2,500
1993	$174,000	$174,000	$12,000	$12,000	$2,000
1992	$482,000	$482,000	$12,000	$12,000	$2,000
1990	$482,000	$482,000	$12,000	$12,000	$2,000

3.2 Assembling Data

After obtaining all the relevant data from TxDOT, the data were assembled for performing the planned analysis. The four step process is described below.

Step 1: Sub Division of Projects

The 230 projects available for analysis were divided into sub categories of “Safety program call years”. Each record dump on the upper left hand corner has a Unique ID – which in part represents the fiscal year in which the project was ranked using the SII formula. Hence sub dividing the 230 projects into their respective program years made sure that the ranking of projects is relative to the same projects they were ranked against originally (leaving behind the unavailable projects).

The 230 available projects span 5 Program Years – 1992, 1994, 1995, 1996, and 1998. Hence, the data were separated into 5 subcategories. The 1992 Program Year had 79 projects, the 1994 Program Year had 38 projects, the 1995 Program Year comprised of 41 projects, the 1996 Program Year had 40 projects, and the 1998 Program Year had the remaining 32 projects. The project entries were entered in Excel and then put in their respective sub categories with all the existing variable information.

Step 2: Selection of Variables and Data Entry

The electronic copies of the record dumps put together by Mr. Danny Morris from the Centre for Transportation Safety at the Texas Transportation Institute were used primarily for another project and hence did not contain some variable entries required for this project, but also contained some entries which were not of use to this project.

Therefore, the entries that were not required by the project, such as – Projected ADT, actual after accident rates, Final Costs among others were removed from the analysis. Some other entries which were required like the Future ADT, Maintenance Cost per year, Total Estimated Cost and the actual SII were added. Each entry was entered manually for all these required entries from the actual record dumps available in paper.

Some problems were encountered during the data collection process. The variables being entered had to be sorted out into their appropriate required form to obtain the SII values correctly in the replicating phase. Changes were made when required but have been documented as part of this thesis in this chapter. For instance, two fields had to be corrected:

ADTs: Most of the record dumps show that the ADT values – present and future are divided into categories based on a functional variable “Class”. If the project had multiple classes of highways involved, the respective ADT values were presented in different lines. The electronic copy of the projects had added these ADTs, but the use of these added values was found to be erroneous at a later stage. TxDOT officials provided information that an average value of these different classes would yield correct values. Hence the entries were modified accordingly.

Maintenance Costs: The record dumps document a total maintenance cost associated with the project. However, the SII formula indicates that the maintenance cost variable included in the formula should be a per year value. Therefore, a value obtained by dividing the total maintenance cost by service life of the project was entered for each project in the data set up.

Step 3: Selecting Crash Costs

As mentioned above, TxDOT provided crash costs for different program years. The program year is in fact not the fiscal year of which crash costs are utilized. The crash costs corresponding to the last year of the 3 period before year a project encompasses are used. The information provided by TxDOT clearly differentiates this and hence the crash costs of the years 1990, 1992, 1993 and 1994 were used for each of the subcategories respectively (1993 crash costs are used for two subcategories – 1995 and 1996). The amounts of dollars used were given in Table 2.

Step 4: Replicating the SII

Given all the information, it was essential to validate the original SII index. As the original SII values for all the projects were available on the record dumps, the formula was applied to the assembled data with necessary inputs and the outcome compared to the original SII values. The SII values of all the projects were replicated successfully with an accuracy of ±0.1. An example calculation is shown here:

Example: Project ID – 1998 01006S (Given SII – 11.03)

Input variables –

Service life – 10 years; Present ADT – 1.325; Future ADT – 1.782;

Fatal Collisions before – 1; Injury Collisions – 2; PDO Collisions – 1;

Crash Costs: Fatal - $200,000; Injury – $16,500; PDO - $2,500

TxDOT CRF – 50; Maintenance Cost per year - $2100; Total Estimated Cost - $26000;

SII Calculations –

$$S = \frac{R(C_f F + C_i I + C_p P)}{Y} - M = \frac{0.5((200000*1)+(16500*2)+(2500*1))}{3} - 2100 = \$37{,}150$$

$$Q = \left(\frac{\frac{A_a - A_b}{A_b}}{L} \right) S = \left(\frac{\frac{1782-1325}{1325}}{10} \right) 37150 = \$1{,}281.325$$

$$B = \frac{S + 1/2Q}{1.08} + \sum_{i=2}^{L} \left[\frac{(S+1/2Q)+(i-1)Q}{(1.08)^i} \right]$$

A calculation of the Benefits is shown below:

First term - $\frac{S+1/2Q}{1.08} = \frac{37150 + (1281.325/2)}{1.08} = \$34{,}991.354$

The Second term value is shown in the table below:

Table 4 - Example SII Calculation

i	Second term
2	33497.9311
3	32033.7596
4	30602.7003
5	29207.8815
6	27851.7865
7	26536.3318
8	25262.9374
9	24032.5899
10	22845.8993
Total	251871.817

The total value of the second term of the benefits formula is \$ 252,871.817. This added to the value of the first term in the formula gives a total benefits value of B = \$286,863.171

Therefore, $SII = \frac{B}{C} = \frac{286863.171}{26000} = 11.0332$

Note: VB Code

Due to the complexity involved in performing a summation each and every time for the analysis, a Visual Basic (VB) code was created to calculate the Benefits value (B) in the SII formula. The Code was written in Excel using the VB editor and acts similar to any preexisting function in Excel, such as "Average". The function requires 4 inputs – Annual savings in crash costs (S), Annual change in crash cost savings (Q), Service life (L), and Interest rate (y). It then calculates the total benefits from the project (B) as the output, which is used to calculate the SII value. Use of this code saved considerable amount of time and effort. The Code used can be found in Appendix E.

3.3 Chapter Summary

This chapter documented the data collection and reduction processes for the analysis. The sources of data were discussed and were followed by a description of the summary statistics. The steps used for data reduction were then discussed.

The following chapter comprises of the description and results of the data analysis performed for this thesis. Few experimental procedures performed on the dataset are also documented in the next chapter.

CHAPTER IV

DATA ANALYSIS

This chapter documents the changes occurring in ranking of projects by performing sensitivity analyses with respect to different variables of the formula. Five variables were chosen for the sensitivity analysis: Interest rate, Dispensing of PDO crashes, Crash Reduction Factors, Accident rate and Crash-Flow relationship.

Each of these variables was modified in a different pattern (keeping other variables constant) and its effects on the ranking of projects were evaluated. The sensitivity analysis performed with respect to each variable is explained in detail in the following paragraphs. However, due to space constraints, only the first cases with respect to each variable analysis are presented and discussed in this chapter. The remaining cases are presented in Appendix A

In addition to the regular sensitivity analysis, this chapter also presents two other experimental analysis and their results. The first procedure involves short listing number of projects based on 80% capitol availability logic. The second experiment involves performing partial derivative analysis on the Benefits in the SII equation and studying the rate of change with respect to the selected variables.

4.1 Sensitivity Analysis

This section is divided into five parts with each part presenting the analysis with respect to one variable.

4.1.1 Interest Rate

As mentioned in Chapter II, the interest rate was believed to be too high and researchers have suggested a flexible interest rate for the ranking process. The projects were ranked and studied by varying the interest rate from 2% to 10% in increasing steps of 1%. The SII values for all projects were calculated in each program year and then were ranked relative to the other projects in the same Program Year. A sample showing the original and changed projects (through project numbers) holding the first 30 projects from each program year is shown in Table 5. The case of modification observed in the example below is a change in the interest rate from an original 8% to 2%. (Note – The project numbers used in this and subsequent tables are unique for each Program Year. The project ID relevant to the number can be found in Appendix F). (Note - The Numbers under each program year correspond to the project numbers and not their SII values.)

Table 5 - Sample Data Table Showing Results for I = 2%

Program Year	1998		1996		1995		1994		1992	
Rank	O	M	O	M	O	M	O	M	O	M
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	38	25	21	44	44
4	1	1	31	31	3	8	21	25	45	45
5	15	15	4	4	38	3	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	34	33	6
8	24	24	34	34	13	26	34	9	6	33
9	27	32	13	25	26	31	3	4	68	68
10	30	27	25	16	14	14	19	3	30	23
11	14	30	16	13	31	13	20	19	23	30
12	2	14	8	8	11	11	4	20	41	5
13	32	2	10	10	40	40	28	33	31	41
14	10	10	14	9	6	6	14	14	5	55
15	3	3	9	14	5	5	30	5	22	31
16	12	12	32	33	7	27	5	28	77	77
17	13	13	33	20	24	41	8	30	73	2
18	17	17	20	32	27	30	33	8	55	9
19	23	29	7	7	41	24	36	10	26	22
20	29	23	1	26	30	7	10	36	2	73
21	8	8	5	1	35	19	16	6	4	26
22	7	6	38	5	19	35	24	15	9	51
23	6	7	26	38	28	28	15	38	69	18
24	20	20	12	12	23	23	32	16	28	4
25	19	19	21	19	39	39	7	24	18	69
26	9	9	19	21	20	32	6	32	51	28
27	31	31	39	29	22	25	38	7	39	39
28	4	4	29	37	17	20	35	18	37	37
29	16	16	37	36	25	22	18	29	64	24
30	28	28	6	22	12	4	31	37	24	64

*O – Original List of Projects; M – Modified List of projects.

From the above table it can be seen that only few projects show a notable change in their ranking in comparison to the original ranking. Most of the projects however retain their original ranks irrelevant of the change made to the variable under test. This is however only a rough estimation and the detailed statistical analysis can be found in Chapter V. Data tables showing similar results with respect to other interest changes observed can be found in Appendix A.

4.1.2 PDO Crashes

Due to the subjective nature of reporting associated with PDO (under reporting), which might affect the ranking process, it was decided to remove PDO crashes from the SII formula might help decrease any discrepancies in the ranking procedure. Hence a modified formula which did not contain the PDO crashes was run on projects to obtain the new SII values and then they were ranked relatively within each program year. The sample data table similar to the above one is provided below. (Note - The Numbers under each program year correspond to the project numbers and not their SII values).

Table 6 - Data Table Showing Results after Removing PDO Crashes

Program Year	1998		1996		1995		1994		1992	
Rank	O	M	O	M	O	M	O	M	O	M
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	30	10	10	22	34	29	33
7	22	22	30	15	33	33	9	22	33	29
8	24	24	34	34	13	13	34	9	6	6
9	27	27	13	13	26	26	3	3	68	68
10	30	14	25	16	14	14	19	19	30	30
11	14	30	16	25	31	31	20	4	23	23
12	2	2	8	8	11	11	4	14	41	31
13	32	3	10	10	40	40	28	20	31	41
14	10	32	14	14	6	6	14	5	5	22
15	3	10	9	9	5	5	30	28	22	5
16	12	12	32	32	7	7	5	30	77	55
17	13	13	33	33	24	27	8	33	73	77
18	17	17	20	20	27	24	33	8	55	2
19	23	23	7	1	41	41	36	36	26	9
20	29	29	1	5	30	30	10	16	2	26
21	8	8	5	26	35	35	16	32	4	73
22	7	7	38	38	19	19	24	6	9	18
23	6	20	26	7	28	28	15	15	69	4
24	20	19	12	12	23	39	32	24	28	51
25	19	6	21	21	39	20	7	10	18	69
26	9	9	19	19	20	23	6	18	51	28
27	31	31	39	29	22	17	38	35	39	39
28	4	4	29	37	17	25	35	7	37	37
29	16	28	37	6	25	22	18	29	64	24
30	28	16	6	39	12	1	31	37	24	10

*O – Original List of Projects; M – Modified List of Projects.

From the above table, it can be seen that only few projects show a notable change in their ranking in comparison to the original ranking. Most of the projects however retain their original ranks irrelevant of the change made to the variable under test. This is however only a rough estimation and the detailed statistical analysis can be found in Chapter V.4.1.3 Crash Reduction Factors.

As discussed in Chapter II, CRFs are considered by many as the most consequential variable related to the SII formulation. Since the study of this subject is out of scope of this research, the current project did not to include examining the reliability of CRFs as an in-depth study variable. However, a smaller scale study which involved randomly varying the CRFs for each project was performed and the resulting rankings were studied.

Using the random number generation tool in Excel, a change in percentage for the CRFs was simulated using a normal distribution with Mean ‘0’ and Standard Deviation ‘0.02’ for each observation. The change in percentage was applied to each CRF and the modified CRFs were used to run the sensitivity analysis. The change was simulated 5 times and each time the analysis was run to examine changes in the ranking.

Having a standard deviation equal to 0.2 meant that the 95% confidence intervals would be +/- 0.392 (39%). Hence, care was taken to eliminate any modified CRFs which would be greater than or equal to 100%, since crashes cannot be eliminated completely (see Lord et al., 2005 on this topic).

A sample dataset portraying the project numbers before and after a change in CRF is shown in Table VII. The table shows results relevant to the first Random Change observed with the CRFs. Other 4 random changes and the results can be found as tables in Appendix A. (Note - The Numbers under each program year correspond to the project numbers and not their SII values).

Table 7 - Sample Data Table Showing Results with Modified CRF - 1

Program Year	1998		1996		1995		1994		1992	
Rank	O	M	O	M	O	M	O	M	O	M
1	21	5	35	2	37	9	27	27	20	29
2	5	21	3	35	9	37	23	21	72	20
3	11	11	2	3	8	3	25	1	44	44
4	1	15	31	4	3	8	21	34	45	72
5	15	14	4	34	38	38	1	9	34	33
6	26	1	15	31	10	10	22	5	29	34
7	22	13	30	13	33	26	9	32	33	4
8	24	2	34	15	13	6	34	33	6	45
9	27	8	13	30	26	33	3	8	68	7
10	30	26	25	33	14	13	19	4	30	30
11	14	24	16	8	31	31	20	28	23	26
12	2	27	8	5	11	5	4	19	41	68
13	32	23	10	14	40	11	28	25	31	73
14	10	19	14	20	6	30	14	22	5	6
15	3	32	9	38	5	7	30	14	22	41
16	12	17	32	9	7	40	5	30	77	23
17	13	16	33	1	24	24	8	35	73	64
18	17	22	20	39	27	19	33	7	55	69
19	23	20	7	22	41	39	36	6	26	2
20	29	10	1	26	30	28	10	37	2	39
21	8	9	5	12	35	41	16	2	4	38
22	7	28	38	32	19	35	24	29	9	51
23	6	6	26	18	28	4	15	38	69	58
24	20	29	12	24	23	20	32	3	28	9
25	19	25	21	17	39	22	7	18	18	5
26	9	18	19	28	20	23	6	10	51	55
27	31	3	39	11	22	25	38	23	39	75
28	4	12	29	23	17	27	35	12	37	77
29	16	31	37	29	25	32	18	24	64	16
30	28	7	6	21	12	29	31	16	24	14

*O – Original List of Projects; M – Modified List of Projects

In this case, it can be observed from the table that most of the projects do exhibit a notable change in their ranks when compared to their original ranks. Only a few projects seem to retain their original ranks. This indicates that a change in CRF might significantly affect the ranking process, this is however only a rough estimation and the detailed statistical analysis can be found in Chapter V.

4.1.4 Accident Rates

The crash counts by severity levels involved in the SII formula are based on a 3 year average. However, it is believed that a long term mean would be a better estimate of the crash frequencies at a project site as it helps minimize the Regression-to-the-mean effect and also eliminate the site selection bias to an extent (Hauer, 1997). The use of long term mean is of proven capacity with the Empirical Bayes method. But, due to the data availability constraints with TxDOT data system, it would not be possible to test this theory with respect to the SII formula. Therefore, similar to the CRFs study, a small scale variation was performed on the crash counts of all severities. The non-zero crash count values were first reduced by 10%, 20% and 30%. The non-zero crash count values were then increased by the same amounts. A sample data set as shown in the above cases is provided here also, with the case being a "-10%" change observed in the accident rate. (Note - The Numbers under each program year correspond to the project numbers and not their SII values).

Table 8 - Sample Data Table Showing Results for Accident Rate = Accident Rate - 0.1

Program Year	1998		1996		1995		1994		1992	
Rank	O	M	O	M	O	M	O	M	O	M
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	24	34	34	13	13	34	34	6	6
9	27	27	13	13	26	26	3	3	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	2	8	8	11	11	4	4	41	41
13	32	32	10	10	40	40	28	28	31	31
14	10	10	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	7	5	5	77	77
17	13	13	33	33	24	24	8	8	73	73
18	17	17	20	20	27	27	33	33	55	55
19	23	29	7	7	41	41	36	36	26	26
20	29	23	1	1	30	30	10	10	2	2
21	8	8	5	5	35	35	16	16	4	4
22	7	7	38	38	19	19	24	24	9	9
23	6	6	26	26	28	28	15	15	69	69
24	20	20	12	12	23	23	32	32	28	28
25	19	19	21	21	39	39	7	7	18	18
26	9	9	19	19	20	20	6	6	51	51
27	31	31	39	29	22	22	38	38	39	39
28	4	4	29	37	17	17	35	35	37	37
29	16	28	37	39	25	25	18	18	64	64
30	28	16	6	6	12	12	31	31	24	24

*O – Original List of Projects; M – Modified List of Projects.

From the above table, it can be seen that only few projects show a notable change in their ranking in comparison to the original ranking. Most of the projects however retain their original ranks irrelevant of the change made to the variable under test. This is however only a rough estimation and the detailed statistical analysis can be found in Chapter V. The remaining observed changes to the accident rate and their results can be found in similar data tables in the Appendix A.

4.1.5 Crash–Flow Relationship

The SII formula portrays a linear relationship between crashes and flow on a roadway system. But it is believed by many that a non linear relationship exists between crashes and flow (Lord, 2002). Thus, the flow variables in the formula are varied non-linearly for analyzing its effects on the ranking procedure. The flow variables are varied with powers of 0.5, 0.6, 0.7, 0.8 and 0.9. Values less than 1.0 are only chosen in this study because even though values greater than 1.0 exist, it is very rarely observed in practice. For a case of $A^{0.5}$, the data table is shown below as sample. The remaining cases can be found in Appendix A. (Note - The Numbers under each program year correspond to the project numbers and not their SII values.)

Table 9 - Sample Data Table Showing Results for Crash Flow Relationship = $A^{0.5}$

Program Year	1998		1996		1995		1994		1992	
Rank	O	M	O	M	O	M	O	M	O	M
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	3	25	25	44	72
4	1	1	31	31	3	8	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	27	34	34	13	13	34	3	6	6
9	27	24	13	13	26	26	3	34	68	68
10	30	14	25	25	14	14	19	19	30	30
11	14	30	16	16	31	31	20	4	23	23
12	2	2	8	8	11	11	4	28	41	31
13	32	10	10	10	40	40	28	14	31	41
14	10	3	14	14	6	6	14	20	5	5
15	3	32	9	9	5	5	30	30	22	22
16	12	12	32	32	7	24	5	5	77	73
17	13	13	33	33	24	7	8	8	73	77
18	17	17	20	20	27	41	33	33	55	26
19	23	23	7	7	41	27	36	36	26	2
20	29	29	1	38	30	30	10	10	2	9
21	8	8	5	1	35	35	16	16	4	4
22	7	7	38	5	19	19	24	24	9	69
23	6	20	26	26	28	28	15	15	69	55
24	20	19	12	12	23	39	32	32	28	51
25	19	6	21	21	39	23	7	7	18	28
26	9	31	19	19	20	20	6	35	51	18
27	31	9	39	39	22	22	38	18	39	39
28	4	4	29	29	17	17	35	6	37	37
29	16	28	37	37	25	25	18	38	64	64
30	28	16	6	6	12	1	31	31	24	24

*O – Original List of Projects; M – Modified List of Projects.

From the above table it can be seen that only few projects show a notable change in their ranking in comparison to the original ranking. Most of the projects however retain their original ranks irrelevant of the change made to the variable under test. This is however only a rough estimation and the detailed statistical analysis can be found in Chapter V.

4.2 Short Listing Experiment

As mentioned earlier, the projects which were not chosen in the selection process for funding were discarded by TxDOT and this restricted the study in identifying the change in ranking with respect to projects not selected. Hence, this small experiment was identified to provide a rough idea of what it would have been like to have had all the data.

For this experiment, it was decided that projects within each program year will be short listed based on the assumption that only 80% of the total funding is available. First, within each program year, the total estimated cost of all the projects was calculated and then 80% of it was set as the criteria for that program year. Then, projects ranked with respect to each variable were sorted along with their estimated costs in ascending order according to the ranking. The estimated costs were then added in a cumulative fashion. When a total cost less than or equal to the 80% is reached, a count of the number of projects not selected was made and entered in a summary table which is provided in this section.

Table 10 provides information on how many projects would not have been selected with respect to each variable change observed. This is shown in each row of the table for all the different program years.

This experiment shows that if the deleted projects were available how drastically a change in a variable would affect a project's position and therefore its eligibility to obtain funding. However, the non deleted projects were analyzed as available and the inference of the tests is provided in the next chapter.

Table 10 - Number of Projects Not Selected Under the 80% Funding Availability Experiment

Program Year / Condition	1998	1996	1995	1994	1992
Original	6	5	4	13	11
I = 0.02	6	5	7	18	16
I = 0.03	6	5	6	17	14
I = 0.04	6	5	5	16	14
I = 0.05	6	5	4	15	14
I = 0.06	6	5	4	13	11
I = 0.07	6	5	4	13	11
I = 0.09	6	5	4	12	11
I = 0.1	6	5	4	12	11
Without PDO crashes	6	5	4	17	14
CRF Random 1	7	8	9	19	24
CRF Random 2	4	4	6	20	15
CRF Random 3	8	6	5	29	17
CRF Random 4	10	7	6	18	22
CRF Random 5	8	9	10	18	13
Accident Rate = Accident Rate - 0.1	6	5	4	13	11
Accident Rate = Accident Rate - 0.2	6	5	4	13	11
Accident Rate = Accident Rate - 0.3	5	5	5	13	11
Accident Rate = Accident Rate + 0.1	5	5	4	5	7
Accident Rate = Accident Rate + 0.2	5	5	4	2	5
Accident Rate = Accident Rate + 0.3	5	5	4	1	4
$A^{0.5}$	6	5	4	11	11
$A^{0.6}$	6	5	4	11	11
$A^{0.7}$	6	5	4	12	11
$A^{0.8}$	6	5	4	12	11
$A^{0.9}$	6	5	4	12	11

The Original condition in the above table refers to the current SII formulation which contains an 8% Interest rate, includes PDO crashes, and uses CRFs observed from TxDOT, uses Accident Rates from a 3 year before period, and has a linear relationship between Crash and Flow variables.

4.3 Partial Derivative Analysis

A partial derivative analysis was performed on the Benefits (B) of the SII equation with respect to three of the five analysis variables discussed in the previous sections. These three variables are Crash Reduction Factors (CRFs), Crash Flow relationship, and Interest rate. This experiment was performed to identify the rate of change associated with these variables to the benefits observed by an average project.

For this experiment the average values for the complete data set as indicated in table 2 were used. The derivative variable was kept constant and the other variables were substituted with their respective average values in the partially derived equation.

The various average values used in the analysis are as follows:

Service Life = L = 14 years;

Future ADT = A_a = 13220; Present ADT = A_b = 18.67;

Fatalities = F = 2.16; Injuries = I = 14.22; PDO crashes = P = 16.15;

Cost of Fatal crashes = C_f = \$302400; Cost of Injury crashes = C_i = \$12900;

Cost of PDO crashes = C_p = \$2100;

CRF = R = 41.39;

Maintenance cost per year = M = \$934.80;

Number of years of crash data = Y = 3;

Crash – Flow relationship = x = 1.0;

The Benefits equation derived with respect to each of the above variables and the rate of change plotted against the variable values are discussed in the following paragraphs.

CRFs: The equation for calculating Benefits in the SII formula is expanded accordingly to represent it in terms of CRFs and hence setup for performing the partial derivation. The equation obtained when derived partially with respect to CRFs (R) is shown below:

$$\frac{\partial B}{\partial R}=\frac{C_f F+C_i I+C_p P}{Y}\left[\frac{1+\frac{1}{2}\left(\frac{\frac{A_a^x-A_b^x}{A_b^x}}{L}\right)}{I_n}+\sum_{i=2}^{L}\frac{1+\frac{1}{2}\left(\frac{\frac{A_a^x-A_b^x}{A_b^x}}{L}\right)}{I_n^i}+\sum_{i=2}^{L}\frac{i-1}{I_n^i}\left(\frac{\frac{A_a^x-A_b^x}{A_b^x}}{L}\right)\right]$$

(Note – The variable "x" used in the above equation is not originally part of the SII equation. It is used only in this section of the thesis for the purpose of this experiment. In this experiment as the exponent of the flow variables is changed from 1 to a different value, this representation is used to study the change occurring due to the partial derivative analysis).

When all the variables in the above equation (except R, which is not present in this equation) are substituted with their average values the equation produces a constant form

$$\frac{\partial B}{\partial R}=2{,}798{,}990\,.$$

When a plot between CRFs and $\frac{\partial B}{\partial R}$ is made a constant line is observed. This produces a trend that indicates that the rate of change of the Benefits with respect to CRFs is constant. The obtained plot is shown in Figure 3.

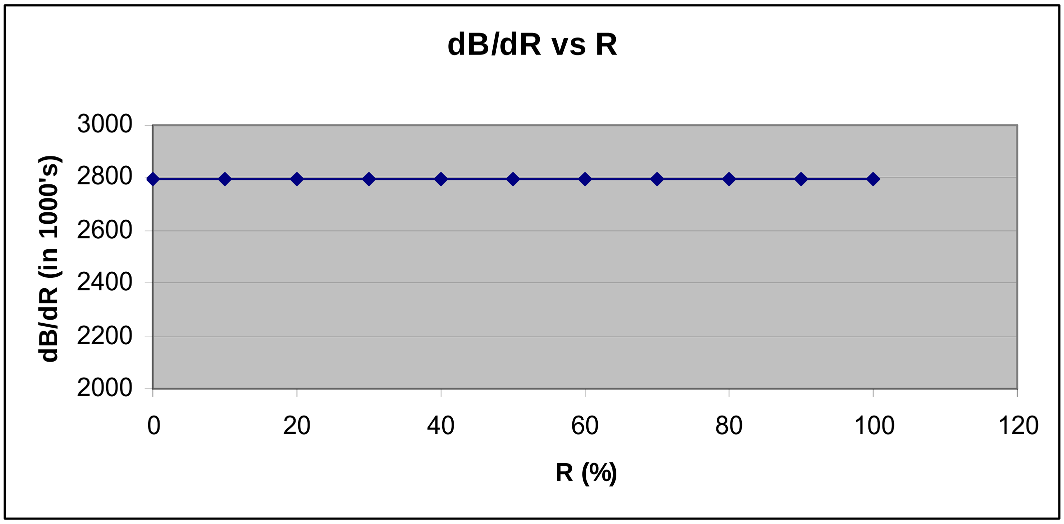

Figure 3 – Plot Showing Rate of Change in Benefits with Respect to CRFs

Crash Flow relationship: The Benefits equation derived partially with respect to the crash flow relationship yields the following format –

$$\frac{\partial B}{\partial x} = \frac{S}{L}\left(\left(\frac{A_a}{A_b}\right)^x \ln\left(\frac{A_a}{A_b}\right)\right)\left[\frac{1}{2I_n} + \sum_{i=2}^{L}\left(\frac{1}{2I_n^i} + \frac{i-1}{I_n^i}\right)\right]$$

Where, $S = \left(\dfrac{C_f F + C_i I + C_p P}{Y} - M\right)$

The equation when supplied with the average values for the variables except x takes the form –

$$\frac{\partial B}{\partial x} = 14093212 \times (1.412254)^x$$

The above equation when plotted against x values varying from 0.5 to 0.9 in steps of 0.1 indicates that the rate of change is positive for the Benefits with respect to x. The plot between the two terms is shown below in Figure 4. (Note – Though the figure appears linear, it is not so and it appears so because of pasting it as a picture in MS – Word)

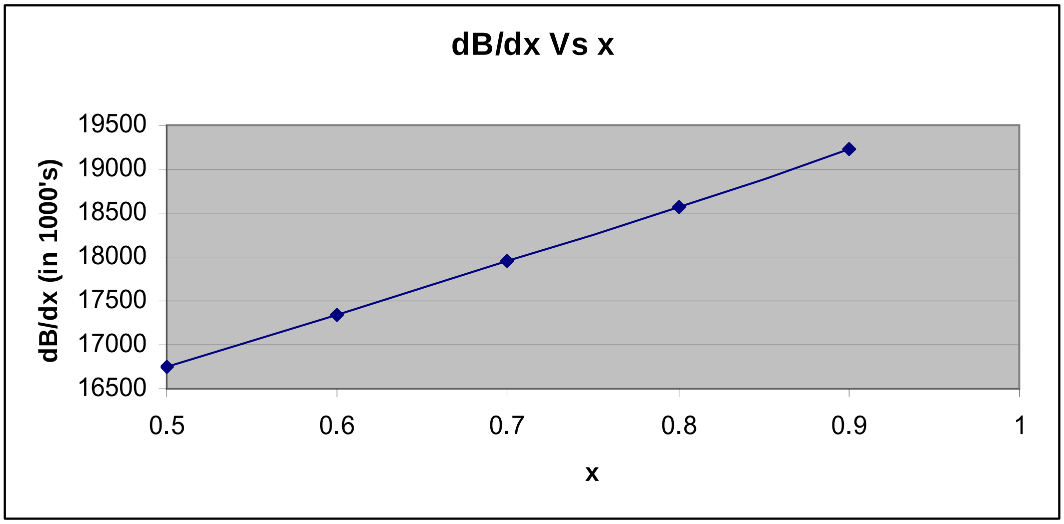

Figure 4 – Plot Showing Rate of Change in Benefits with Respect to Crash-Flow Relationship

Interest Rate: Similar to the above two cases, the equation for Benefits is derived with respect to Interest rate in this case. The equation obtained in its variable form after derivation is as follows –

$$\frac{\partial B}{\partial I_n} = S\left[\left(1+\frac{1}{2}\left(\frac{\frac{A_a^x - A_b^x}{A_b^x}}{L}\right)\times\left(\frac{-1}{I_n^2}\right)\right)+\left(\left(1+\frac{1}{2}\left(\frac{\frac{A_a^x - A_b^x}{A_b^x}}{L}\right)\right)\times\sum_{i=2}^{L}\left(\frac{-i}{I_n^{i+1}}\right)\right)+\left(\left(\frac{\frac{A_a^x - A_b^x}{A_b^x}}{L}\right)\times\sum_{i=2}^{L}\left(\frac{-i(i-1)}{I_n^{i+1}}\right)\right)\right]$$

Where, $S = \dfrac{C_f F + C_i I + C_p P}{Y} - M$.

The equation substituted with the respective average values, except I_n, and plotted against interest rates from 2% to 10% in the steps of 1% yielded that the rate of change is positive. Hence, the change in Benefits with respect to change in interest rate possesses an increasing effect, but at a decreasing rate. The plot for the above case is shown below in Figure 5.

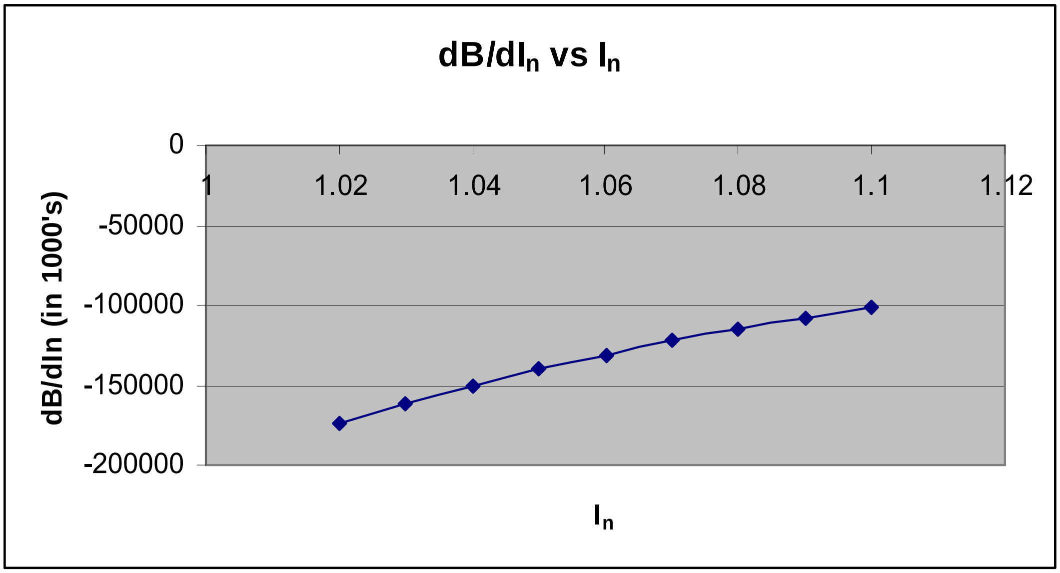

Figure 5 – Plot Showing Rate of Change in Benefits with Respect to Interest Rate

4.4 Chapter Summary

This chapter documented the results of three analyses. The first analysis consisted of examining the ranking of projects between the initial conditions and the adjusted variable conditions. This analysis comprised of studying the change in ranking of projects with respect to five critical variables in the SII formula: Interest rate, Dispensing of PDO crashes, Crash Reduction Factors, Accident rate and Crash-Flow relationship. Each variable was modified in a different pattern and the resulting changes in the ranking were studied. From the analysis it was observed that most of the cases did not result in any notable change in the ranking of the projects, except for cases related to modifying the CRF values used. The cases dealing with modified CRFs showed a tendency to influence the ranking.

The second analysis shows that if the deleted projects were available how drastically a change in a variable would affect a project's position and therefore its eligibility to obtain funding. For this experiment, projects within each Program Year were short listed based on the assumption that only 80% of the total funding is available. Results were presented to show how many projects within each Program Year would not have qualified for funding based on this assumption.

The third analysis was performed to identify the rate of change associated with some of these critical variables to the Benefits (B) observed by an average project. The analysis was carried out with respect to three of the five critical variables - Crash Reduction Factors (CRFs), Crash Flow relationship, and Interest rate. It was observed from the analysis results that CRFs displayed a constant rate of change, Crash flow relationship displayed a positive rate of change and the Interest rate displayed a decreasing rate of change on the Benefits (B).

The results observed in the first analysis above were merely results. The statistical significance of these results will be studied and presented in the next chapter with the use of several statistical tests.

CHAPTER V

STATISTICAL INTERPRETATION AND INFERENCE

The main objective of this chapter is to compare the rankings of projects between initial conditions and modified conditions and evaluate whether the change in rankings is statistically significant or not. Hence, two statistical tests were used – Spearman Rank Order Correlation Test and Kendall's Rank Correlation.

5.1 Spearman Rank Order Correlation Test

The Spearman's rank correlation coefficient, named after Charles Spearman and often denoted by the Greek letter ρ (ρ), is a non-parametric measure of correlation – that is, it assesses how well an arbitrary monotonic function could describe the relationship between two variables (in this case – SII and its ranking), without making any assumptions about the frequency distribution of the variables (Freund, 1992). Here the coefficient ρ is given by –

$$\rho = 1 - \frac{6\sum d_i^2}{n\left(n^2 - 1\right)}$$

Where,

d_i = the difference between each rank of corresponding values of x and y, and

n = the number of pairs of values.

Note: If tied ranks exist, the same rank is assigned to each of the equal values. This same rank is an average of their positions in the ascending order of the values.

Testing for significance: The modern approach to testing whether an observed value of ρ is significantly different from zero (we will always have $1 \geq \rho \geq -1$) is to calculate the probability that it would be greater than or equal to the observed ρ, given the null hypothesis, by using a permutation test. This approach is almost always superior to traditional methods, unless the data set is so large that computing power is not sufficient to generate permutations, or unless an algorithm for creating permutations that are logical under the null hypothesis is difficult to devise for the particular.

In this thesis a z-test is used for testing significance. A z-value is calculated for each case with the equation $- z = \rho\sqrt{n-1}$. The z-value obtained is tested against the 95% significance – which has a z-value of 1.96, the null hypothesis being there is no correlation between SII and its ranking. Also, the z-value obtained is converted into p-value and tested for significance against the critical p-value.

5.2 Kendall's Rank Correlation

This correlation provides a distribution free test for independence which also provides a measure of the strength of dependence between two variables. Like the Spearman rank correlation coefficient, Kendall's τ is based on the ranks of observations, and it can assume values between -1 and +1. Spearman's rank correlation is satisfactory for testing a null hypothesis of independence between two variables but it is difficult to interpret when the null hypothesis is rejected. Kendall's rank correlation improves upon this by reflecting the strength of the dependence between the variables being compared.

The parameter estimated by τ may be defined as the probability of concordance minus the probability of discordance. The observation pairs (X_i, Y_i) and (X_j, Y_j) are said to be concordant if the difference between X_i and X_j is in the same direction as the difference between Y_i and Y_j, and if not – they are said to be discordant. The test statistic - τ, the measure of association is given by the equation –

$$\tau = \frac{n_c - n_d}{n(n-1)/2}$$

Where,

n_c = Number of concordant pairs.

n_d = Number of discordant pairs.

n = Number of observations/pairs.

In this thesis, the value of τ is obtained for all the cases under study by using the software SAS (SAS, 2002). Consequently using the τ values, the percentage of concordant pairs is found using the equation $-\frac{\tau+1}{2}$. Multiplying this percentage by the number of observations in each case, the number of pairs which showed no change in their ranking is obtained. This is thus used as an estimate to judge if a change in the variable is leading to a significant number of projects showing change.

5.3 Interpretation and Inference of Results

Using the above two tests, comparative statistics were run over outputs from the data analyses. For this, the rankings of projects were paired with the original rankings and the test statistics were run on the pair to study for any correlation and similarity. The Spearman's test studied the existence of a correlation, while the Kendall's test discusses a measure of the correlation.

As mentioned above, for the Spearman's test the null hypothesis is stated as –
H_0: No correlation exists between SII and its rankings. When using z-statistics, if the value of z-calculated is < value of z-critical, accept H_0. When using p-value, if p-calculated is > p-critical (0.05), accept H_0.

The Kendall's test is however a more descriptive measure and thus provides us with an estimation of how many pairs retain the original ranking and how many pairs indicate a change, in other words – number of concordant pairs and number of discordant pairs.

Note: The test statistics are shown for each case at the bottom in the data tables.

The interpretation and relevant inference with respect to each variable analysis is discussed in the following paragraphs of this chapter. The variables investigated are the same five critical variables used in the data analysis: Interest rate, Dispensing of PDO crashes, Crash Reduction Factors, Accident rate and Crash-Flow relationship. Similar to the explanation in the data analysis chapter, a sample data table is provided to illustrate the tests and a complete set of tables can be found in Appendix B.

5.3.1 Interest Rate

It was found from the statistical tests that there exists a correlation between SII and the corresponding ranks in all the cases tested, but also that there is no difference in the rankings compared to the original rankings when a change in interest rate was observed. All the pairs tested showed that a change in the interest rate would not necessarily change the rankings and hence the current interest rate is adequate. The Kendall's test indicates the number of projects which showed a change in their ranking when a change was observed in the original formulation. With respect to changes in Interest rate, no significance change in rankings was observed with the Kendall's test, more than 99% of the projects appeared to have retained their ranking.

A sample data set showing the Spearman and Kendall tests comparing the rankings of projects for all the program years over the interest rates 8% and 2% is shown below. Other data sets compiled over the other changes can be found in Appendix B.

Table 11 - Sample Data Table Showing Statistical Inferences for I = 2%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d^2)	24	sum(d^2)	134	sum(d^2)	300	sum(d^2)	168	sum(d^2)	1370
	ρ	0.9956	ρ	0.9874	ρ	0.9739	ρ	0.9816	ρ	0.9833
	z-value	5.5433	z-value	6.1665	z-value	6.1593	z-value	5.9709	z-value	8.6845
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation	
	reject h_0		reject h_0		reject h_0		reject h_0		reject h_0	
Kendall's	τ	0.976	τ	0.936	τ	0.893	τ	0.903	τ	0.912
	(τ+1)/2	0.988	(τ+1)/2	0.968	(τ+1)/2	0.946	(τ+1)/2	0.952	(τ+1)/2	0.95583
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	39	No. of pairs retaining rank	36	No. of pairs retaining rank	76
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	2	No. of pairs showing change	2	No. of pairs showing change	3

5.3.2 PDO Crashes

Similar to the case of interest rate, no difference in the rankings was observed with the removal of PDO crashes from the SII equation. All the sets tested showed the same results. The Kendall's test indicates the number of projects which showed a change in their ranking when a change was observed in the original formulation. More than 99% of the projects retained their ranking in this scenario as well.

The data set for this case is shown in the following table which contains Spearman's test in the top half and then Kendall's test in the bottom half. The Kendall's test contains four rows of data, first one showing the calculated value of τ, followed by the value of $(\tau+1)/2$. Next, the number of pairs which retained their rankings were shown followed by a listing of the number of pairs which showed some change in their rankings. This is shown for all the five program years.

Table 12 - Data Table Showing Statistical Inferences after Removing PDO Crashes

Test	1998		1996		1995		1994		1992	
Spearman	sum(d^2)	20	sum(d^2)	50	sum(d^2)	38	sum(d^2)	136	sum(d^2)	1558
	ρ	0.9963	ρ	0.9953	ρ	0.9967	ρ	0.9851	ρ	0.9810
	z-value	5.5474	z-value	6.2157	z-value	6.3036	z-value	5.9922	z-value	8.6643
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation	
	reject h_0		reject h_0		reject h_0		reject h_0		reject h_0	
Kendall's	τ	0.968	τ	0.967	τ	0.971	τ	0.915	τ	0.895
	$(\tau+1)/2$	0.984	$(\tau+1)/2$	0.983	$(\tau+1)/2$	0.985	$(\tau+1)/2$	0.957	$(\tau+1)/2$	0.947385
	No. of pairs retaining rank	31	No. of pairs retaining rank	39	No. of pairs retaining rank	40	No. of pairs retaining rank	36	No. of pairs retaining rank	75
	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	2	No. of pairs showing change	4

5.3.3 Crash Reduction Factors

It was observed that even a random variation induced on CRFs altered the rankings of the projects quite significantly. The Kendall's tests conducted on all the sets revealed that a change in CRF value altered the current rankings by an average of 26%. This indicates that on an average 26% of the projects showed a change in their ranking when a change in CRF was observed. Thus, the statistical test for this case shows that a highly variable CRF could affect the ranking.

A data set showing results of the first random generated change to the CRF for all years is provided below as a sample. The data set shown below contains Spearman's correlation test in the top half and then Kendall's correlation test in the bottom half. Other results with respect to the other random generations can be found in Appendix B attached at the end of this report.

Table 13 - Sample Data Table Showing Statistical Inferences for Modified CRF 1

Test	1998		1996		1995		1994		1992	
Spearman	sum(d^2)	1818	sum(d^2)	3880	sum(d^2)	1570	sum(d^2)	3617	sum(d^2)	25142
	ρ	0.6668	ρ	0.6360	ρ	0.8632	ρ	0.6042	ρ	0.6940
	z-value	3.7125	z-value	3.9720	z-value	5.4596	z-value	3.6753	z-value	6.1291
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0002	p value	0.0001	p value	0.0001	p value	0.0002	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation	
	reject h_0		reject h_0		reject h_0		reject h_0		reject h_0	
Kendall's	τ	0.512	τ	0.508	τ	0.746	τ	0.450	τ	0.524
	$(\tau+1)/2$	0.756	$(\tau+1)/2$	0.754	$(\tau+1)/2$	0.873	$(\tau+1)/2$	0.725	$(\tau+1)/2$	0.762175
	No. of pairs retaining rank	24	No. of pairs retaining rank	30	No. of pairs retaining rank	36	No. of pairs retaining rank	28	No. of pairs retaining rank	60
	No. of pairs showing change	8	No. of pairs showing change	10	No. of pairs showing change	5	No. of pairs showing change	10	No. of pairs showing change	19

5.3.4 Accident Rate

The statistical tests infer that a change in Accident Rate would not alter the rankings to a level of statistical significance. The Kendall's test indicates the number of projects which showed a change in their ranking when a change was observed in the original formulation. Interestingly, only the program years 1994 and 1992 displayed a variation of around 24% in few cases. In spite of the above mentioned differences, it was observed that more than 99% of the projects retained their ranking in an individual scenario.

A sample data set of the analysis is presented in the following table while the other cases can be found in Appendix B attached at the end of this report. The data set shown below contains Spearman's correlation test in the top half and then Kendall's correlation test in the bottom half.

Table 14 - Sample Data Table Showing Statistical Inferences for Accident Rate = Accident Rate - 0.2

Test	1998		1996		1995		1994		1992	
Spearman	sum(d^2)	8	sum(d^2)	12	sum(d^2)	4	sum(d^2)	2	sum(d^2)	1
	ρ	0.9985	ρ	0.9989	ρ	0.9997	ρ	0.9998	ρ	1.0000
	z-value	5.5596	z-value	6.2380	z-value	6.3224	z-value	6.0814	z-value	8.8317
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation	
	reject h_0		reject h_0		reject h_0		reject h_0		reject h_0	
Kendall's	τ	0.984	τ	0.987	τ	0.995	τ	0.997	τ	1.000
	(τ+1)/2	0.992	(τ+1)/2	0.994	(τ+1)/2	0.998	(τ+1)/2	0.999	(τ+1)/2	0.99992
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

5.3.5 Crash–Flow Relationship

The use of a non-linear relationship between crash and traffic flow in the SII equation did not alter the rankings of projects from their original ranks. All the data sets compared showed that there was no statistically significant difference. Therefore a linear relationship seems to be adequate for ranking projects.

Similar to the other cases, a sample data set (for the case of $A^{0.5}$) is provided below and the remaining cases are provided in Appendix B. The data set shown below contains Spearman's correlation test in the top half and then Kendall's correlation test in the bottom half. The Kendall's test contains four rows of data, first one showing the calculated value of τ, followed by the value of $(\tau+1)/2$. Next, the number of pairs which retained their rankings were shown followed by a listing of the number of pairs which showed some change in their rankings. This is shown for all the five program years.

Table 15 - Sample Data Table Showing Statistical Inferences for Crash Flow Relationship - $A^{0.5}$

Test	1998		1996		1995		1994		1992	
Spearman	sum(d^2)	22	sum(d^2)	14	sum(d^2)	34	sum(d^2)	30	sum(d^2)	183
	ρ	0.9960	ρ	0.9987	ρ	0.9970	ρ	0.9967	ρ	0.9978
	z-value	5.5453	z-value	6.2368	z-value	6.3058	z-value	6.0628	z-value	8.8121
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation		h_0 = no correlation	
	reject h_0		reject h_0		reject h_0		reject h_0		reject h_0	
Kendall's	τ	0.964	τ	0.987	τ	0.971	τ	0.977	τ	0.967
	$(\tau+1)/2$	0.982	$(\tau+1)/2$	0.994	$(\tau+1)/2$	0.985	$(\tau+1)/2$	0.989	$(\tau+1)/2$	0.98368
	No. of pairs retaining rank	31	No. of pairs retaining rank	40	No. of pairs retaining rank	40	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	1

5.4 Chapter Summary

This chapter presented the statistical results and their significance with respect to the sensitivity analysis performed. A brief discussion about the different statistical tests used in this thesis was first presented in this chapter, followed by the statistical tests and their results with respect to each variable investigated. The statistical tests showed that, with the exception of CRFs, all changes in the values of variables investigated did not affect significantly the ranking of projects.

CHAPTER VI

SUMMARY, DISCUSSION AND RECOMMENDATIONS

This chapter describes the work preformed in this thesis; provides a discussion about the major conclusions; and, presents recommendations for further work.

6.1 Summary

This section provides a brief summary of the work accomplished in this thesis. The objective of this thesis was to evaluate the SII in its current functional form, retaining the original values of the variables, and usefulness to rank and prioritize projects for safety improvement.

Chapter II presented a review of the literature available on and relevant to the topic of SII from different time frames, jurisdictions and research studies. The application of HES program in Texas and other states of the United States was documented. The focus was then shifted to critically studying the SII formula for identifying potential issues related to the ranking process. In this process, some issues related to the SII and also few suggestive measures were described.

Chapter III documented the data collection and reduction processes for the analysis. The sources of data were discussed. The chapter also included a description of the summary statistics for the variables used in this thesis. The steps used for reducing the data were then discussed. Five program years were evaluated which had a total of 230 projects.

Chapter IV documented the results of three analyses. The first analysis consisted of examining the ranking of projects between the initial conditions and the adjusted variable conditions. Each variable was investigated one at the time. From the analysis, it was observed that, in most cases, no notable changes in the ranking of the projects, with the exception of CRF values, were noted. The cases dealing with modified CRFs showed a tendency to influence the ranking.

The second analysis in chapter IV consisted in determining how many projects out of the ones ranked by the original SII would be funded if a specific budget was allocated when variables are changed. For this analysis, projects within each Program Year were short listed based on the assumption that only 80% of the total funding is available. The results indicated that less than 10% of projects may not have been funded when values of certain variables are changed in the SII.

The third analysis in chapter IV was performed to identify the rate of change associated with some of these critical variables to the Benefits (B) observed by an average project. The analysis was carried out with respect to three of the five critical variables - CRFs, Crash Flow relationship, and Interest rate. It was observed from the analysis results that CRFs displayed a constant rate of change, Crash flow relationship displayed a positive rate of change and the Interest rate displayed a function that increased at a decreasing rate of change on the Benefits (B).

Chapter V presented the statistical results and their significance with respect to the sensitivity analysis performed in Chapter IV. A brief discussion about the different statistical tests used in this thesis was first presented in this chapter. This was followed by the application of these statistical tests and their results with respect to each variable investigated. The Spearman’s Rank Order Correlation Test and The Kendall’s Tau Coefficient were the two statistical methods used in the thesis. The Spearman’s test was used to identify any correlation between the SII values and their rankings. And the Kendall’s Tau Coefficient was used to identify the measure of association between the variables. The statistical tests showed that, with the exception of CRFs, all changes in the values of variables investigated did not affect significantly the ranking of projects.

6.2 Discussion

The results documented in this thesis show that, although the SII is influenced by changes in the value of each variable, the ranking of projects usually remains the same or changes slightly. The two statistical tests indicate that these slight changes are not statistically significant, with the exception of CRFs (discussed below). However, in one of the analyses performed in this work, it was observed that projects that were originally ranked near the cut-off point (i.e., the point where the funds are depleted) may no longer be funded when variables are changed in the SII. The analysis showed that up to 11% of the original projects may not be funded in extreme cases. Thus, these cut-off points may be examined more closely, if other values of are used in the SII.

As discussed above, the CRF variable was the only variable that seriously affected the ranking of project (in a statistical manner). As document in Chapter II, there exist many issues with the development and application of these factors. Although the accuracy and reliability of CRFs are beyond the scope of this project, their development and use in the SII need to be closely examined. Using unreliable CRFs may lead to projects that are selected for improvement, but should not have been. Hence, this will lead to a waste of funds and the opportunity to reduce injuries and societal costs associated with motor vehicle collisions. Recent work conducted by TTI indicated that CRFs seemed to be unreliable when projects funded by the HSIP were evaluated after they we implemented (Hofener et al. 2003).

Given the results documented in this thesis, changes to the current formulation are not recommended as changes made to any variables in the index would not affect the ranking of the projects submitted by the various districts. Therefore, it is recommended that the current formulation of the SII be retained by TxDOT for prioritizing safety improvement projects at this point in time. This does not mean however that other functional forms that include more or different input variables, if available in TxDOT databases, should not be evaluated.

Nevertheless, it is suggested to perhaps conduct sensitivity analyses by ranking projects several times using different values for the input variables (particularly the one used for the CRFs), before finalizing the list of projects for funding. A final list of projects could be selected based on the results of these analyses – as only the projects which show stability in their ranking based on these different rankings could be funded.

Projects which show inconsistency in their ranking (especially those near the cut-off point) should be examined for more details and, perhaps, not be selected for funding. This procedure may minimize the bias associated with the selection process.

6.3 Recommendations

Certain recommendations suggested for enhancing the quality of the formula and thus the services it provides are stated as follows –

- Given its influence on the ranking of projects, the reliability and accuracy of CRFs should be studied in more detail, starting from their development process.
- It is recommended that other methods used by other states should be evaluated with the current formulation of the SII. These methods often incorporate other variables not used by TxDOT. However, data limitations with respect to certain variables provide hindrances. Thus, a system to collect these additional data is also recommended.
- TxDOT should incorporate decision theory in the ranking of projects submitted for the SII. Decision theory incorporates uncertainty associated with variables that are used for making decisions and the consequences attributed to an erroneous decision. Hence, in this context, including concepts associated with the SII may improve the selection process in selecting projects for safety improvements.
- Some new methods for prioritizing projects were discussed in this report which should be examined in the future and study their applicability for the case in hand, and compare the ranking with the current method. Testing these new methods was beyond the scope of this study, since some data were not available.
- Finally, it is recommended that the evaluation of such methods be conducted in some future point of time, if the additional data, not used in the current SII, become available.

REFERENCES

Barbaresso, C. J., Brent, B.O., Mann, C.R., Smith, G. 1982. Selection process for local highway safety projects. Transportation Research Record 847, 24-29.

Breyer, J.P. 2000. Tools to identify safety issues for a corridor safety-improvement program. Transportation Research Record 171, Paper No. 00-0474.

Brijs, T., Karlis, D., Van den Bossche, F., Wets, G. 2003. A bayesian model for ranking hazardous sites. Flemish Research center for traffic safety, Diepenbeek, Belgium.

Brijs, T., Wets, G., Guerts, K., Koen, V. 2004. Identification and ranking of black spots: Sensitivity analysis. Transportation Research Record 1897, 34-42.

California Department of Transportation. 2005. Hazard elimination safety (HES). Caltrans local assistance program guidelines.

Counci,l F.M., Reinfurt, D.W., Campbell, B.J., Roediger, F.L., Carroll, C.L., Amitabh, K.D., Dunham, J.R. 1980. Accident research manual. Highway safety research center, University of North Carolina.

De Leur, P., Tarek, S. 2002. Development of a road safety risk index. Transportation Research Record 1784, Paper No. 02-2814.

Falcocchio, J.C., Michel, R.M., Levinson, H.S., Assefa, S. 1994. Priority ranking of problem intersections in Brooklyn, N.Y. ITE Journal, volume 64, issue 5, 20-25.

Federal Highway Association. March 1979. Federal-Aid Highway Program Manual, Volume 8, Chapter 2, Section 3 (FHPM 8-2-3).

Freund, J.E. 1992. Mathematical statistics. A prentice hall publication.

Hallmark, L.S., Basavaraju, R. June 2002. Evaluation of the Iowa DOT's safety improvement candidate list process. Final report, CTRE Project 00-74.

Hanley, E.K., Gibby, A.R., Ferrara, C.T. 2000. Analysis of accident-reduction factors on California state highways. Transportation Research Record 1717, Paper No. 00-0510.

Hauer, E., Persaud, B.N. 1984. Problem of identifying hazardous locations using accident data. Transportation Research Record 975, pp. 36-43.

Hauer, E. 1996. Identification of sites with promise. Transportation Research Record 1542, 54-60.

Hauer, E., 1997. Observational before-after studies in road safety. Peragamon Publications, England.

Hauer, E., Allery, K.B., Kononov, J., Griffith, M.S. 2004. How best to rank sites with promise. Transportation Research Record 1897, 48-53.

Hofener, M.S., Griffin, L.I. – III, Mounce, J.M. August 2003. Evaluation of hazard elimination safety program crash reduction factors for safety improvement index calculations. TxDOT final report No. 150303 – 1.

Homburger, S., Wolfgang, J., Hall, W.R, Loutzenheiser, C., William, R.R. May 1996. Fundamentals of traffic engineering. Institute of Transportation Studies, University of California Berkeley.

Layton, R.D. Decemeber 1996. An evaluation of the safety priority index system. Traffic Management Section, Oregon Department of Transportation.

Li, X., Yu, L., Garg, V. 2004. Evaluation of the overall effectiveness of highway safety improvement projects at the national level. Published for American Society of Civil Engineers.

Lord, D. 2002. Issues related to the application of accident prediction models for the computation of accident risk on transportation networks. Transportation Research Record 1784, 17-26.

Lord, D., Bonneson, J.A. 2005. Role and application of accident modification factors in the highway design process. TTI Report FHWA/TX-05/0-4703-2.

Lord, D., Bonneson, J.A. 2005. Role and application of accident modification factors (AMFs) within the highway design process. Paper presented at the 85th Annual Meeting of the Transportation Research Board.

Lord, D., Washington, S.P., Ivan J.N. 2005. Poisson, poisson-gamma and zero inflated regression models of motor vehicle crashes: Balancing statistical fit and theory. Accident Analysis & Prevention. Vol. 37, No. 1, 35-46.

Lu, J.J., Pernia J. June 1999. Development of a new procedure to prioritize intersection safety improvement projects. Southeastern Transportation Center.

McMillen, R.D. 1999. Statistical evaluation in traffic safety studies. Informational Report, Institute of Transportation Engineers.

Mounce, J. 2005. Evaluation of hazard elimination safety program crash reduction factors. ITE 2005 Annual Meeting and Exhibit Compendium of Technical Papers.

Mountain, L., Fawaz B. 1992. The effect of engineering measures on safety at adjacent sites. Traffic Engineering & Control, Vol. 33, No. 1, 10-14.

NCHRP. 1986. Methods for Identifying Hazardous Highway Elements. National Cooperative Highway Research Program Report 128, 80p.

NCHRP. 2000. Accident mitigation guide for congested rural two-lane highways. National Cooperative Highway Research Program Report 440, 64p.

Niessner, W.C. 2005. Research results digest 299. National Cooperative Highway Research Program.

Ogden, K.W. 1996. Safer roads: A guide to road safety engineering. Avebury Technical, Aldershot, England.

Persaud, B.N., Lyon, C., Nguyen, T. 1999. Empirical bayes procedure for ranking sites for safety investigation by potential for safety improvement. Transportation Research Record 1665, 7-12.

RSM. 2003. Road safety manual. PIARC technical committee on road safety.

SAS Institute Inc. 2002. Version 9 of the SAS System for Windows. Cary, NC.

SEMCOG. September 1997. Traffic Safety Manual (Second Edition). Southeast Michigan Council of Governments, Detroit, MI.

Shen, J., Rodriguez, A., Gan, A. November 2003. Development and application of crash reduction factors: A state-of-the-practice survey of state departments of transportation. Presented at the 83rd Annual Meeting of the Transportation Research Board.

Shen, J., Rodriguez, A., Gan, A. April 2005. Update of Florida crash reduction factors and countermeasures to improve the development of district safety improvement projects. Final Report Submitted to the Florida Department of Transportation.

Stokes, R.W., Madaniyo, I.M. February 2004. Rate-quality control method of identifying hazardous road locations. Transportation Research Record 1542, 44-48.

Traffic Accident Information and Hazard Elimination Manual. February, 2004. Texas Department of Transportation.

Tarko, A., Sinha, C.K., Farooq, O. 1996. Methodology for identifying highway safety problem areas. Transportation Research Record 1542, 49-53.

Tarko, A., Eranky, S., Sinha, C.K. 1998. Methodological considerations in the development and use of crash reduction factors. Paper Presented at the 77th Annual Meeting of the Transportation Research Board.

Thomas, G.B., Smith, D.J., Welch, T.M. October 2001. Effectiveness of intersection safety improvements using crash reduction factors and benefit cost ratios. Iowa DOT's Report.

Traffic Institute. November 1999. Program of instruction for the workshop on identification and treatment of high hazard locations. The Traffic Institute, Northwestern University, Evanston, IL.

Traffic Institute. 2000. Program of instruction for the workshop on identification and treatment of high hazard locations. The Traffic Institute, Northwestern University, Evanston, IL.

APPENDIX A

SENSITIVITY ANALYSIS: RESULTS

Sample Data Table Showing Results for I = 3%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	38	25	21	44	44
4	1	1	31	31	3	8	21	25	45	45
5	15	15	4	4	38	3	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	34	33	6
8	24	24	34	34	13	26	34	9	6	33
9	27	27	13	25	26	14	3	4	68	68
10	30	30	25	16	14	31	19	3	30	23
11	14	32	16	13	31	13	20	19	23	30
12	2	14	8	8	11	11	4	20	41	5
13	32	2	10	10	40	40	28	14	31	41
14	10	10	14	9	6	6	14	33	5	31
15	3	3	9	14	5	5	30	28	22	55
16	12	12	32	33	7	27	5	5	77	77
17	13	13	33	20	24	41	8	30	73	22
18	17	17	20	32	27	24	33	8	55	2
19	23	29	7	7	41	30	36	10	26	9
20	29	23	1	26	30	7	10	36	2	73
21	8	8	5	1	35	19	16	15	4	26
22	7	6	38	5	19	35	24	6	9	51
23	6	7	26	38	28	28	15	38	69	4
24	20	20	12	12	23	23	32	16	28	18
25	19	19	21	19	39	39	7	24	18	69
26	9	9	19	21	20	25	6	32	51	28
27	31	31	39	29	22	32	38	7	39	39
28	4	4	29	37	17	20	35	18	37	37
29	16	16	37	36	25	22	18	29	64	24
30	28	28	6	22	12	17	31	37	24	64

Sample Data Table Showing Results for I = 4%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	21	44	44
4	1	1	31	31	3	38	21	25	45	45
5	15	15	4	4	38	3	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	34	33	33
8	24	24	34	34	13	26	34	9	6	6
9	27	27	13	13	26	13	3	3	68	68
10	30	30	25	25	14	14	19	4	30	23
11	14	14	16	16	31	31	20	19	23	30
12	2	32	8	8	11	11	4	20	41	5
13	32	2	10	10	40	40	28	14	31	41
14	10	10	14	14	6	6	14	28	5	31
15	3	3	9	9	5	5	30	33	22	55
16	12	12	32	33	7	27	5	5	77	77
17	13	13	33	32	24	41	8	30	73	22
18	17	17	20	20	27	24	33	8	55	2
19	23	23	7	7	41	30	36	36	26	9
20	29	29	1	26	30	7	10	10	2	73
21	8	8	5	1	35	19	16	15	4	26
22	7	6	38	5	19	35	24	16	9	4
23	6	7	26	38	28	28	15	6	69	51
24	20	20	12	12	23	23	32	24	28	18
25	19	19	21	21	39	39	7	38	18	69
26	9	9	19	19	20	25	6	32	51	28
27	31	31	39	29	22	20	38	7	39	39
28	4	4	29	37	17	32	35	18	37	37
29	16	16	37	36	25	22	18	35	64	64
30	28	28	6	18	12	17	31	29	24	24

Sample Data Table Showing Results for I = 5%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	15	4	4	38	38	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	34	33	33
8	24	24	34	34	13	26	34	9	6	6
9	27	27	13	13	26	13	3	3	68	68
10	30	30	25	25	14	14	19	4	30	23
11	14	14	16	16	31	31	20	19	23	30
12	2	32	8	8	11	11	4	20	41	5
13	32	2	10	10	40	40	28	14	31	41
14	10	10	14	14	6	6	14	28	5	31
15	3	3	9	9	5	5	30	33	22	77
16	12	12	32	33	7	27	5	5	77	55
17	13	13	33	32	24	41	8	30	73	22
18	17	17	20	20	27	24	33	8	55	73
19	23	23	7	7	41	7	36	36	26	2
20	29	29	1	26	30	30	10	10	2	9
21	8	8	5	1	35	19	16	15	4	26
22	7	6	38	5	19	35	24	16	9	4
23	6	7	26	38	28	28	15	24	69	51
24	20	20	12	12	23	23	32	6	28	18
25	19	19	21	21	39	39	7	32	18	69
26	9	9	19	19	20	20	6	38	51	28
27	31	31	39	29	22	25	38	7	39	39
28	4	4	29	37	17	22	35	18	37	37
29	16	16	37	36	25	17	18	35	64	64
30	28	28	6	39	12	12	31	29	24	24

Sample Data Table Showing Results for I = 6%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	15	4	4	38	38	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	9	33	33
8	24	24	34	34	13	26	34	34	6	6
9	27	27	13	13	26	13	3	3	68	68
10	30	30	25	25	14	14	19	19	30	23
11	14	14	16	16	31	31	20	4	23	30
12	2	32	8	8	11	11	4	20	41	41
13	32	2	10	10	40	40	28	14	31	5
14	10	10	14	14	6	6	14	28	5	31
15	3	3	9	9	5	5	30	5	22	22
16	12	12	32	32	7	27	5	33	77	77
17	13	13	33	33	24	24	8	30	73	55
18	17	17	20	20	27	41	33	8	55	73
19	23	23	7	7	41	7	36	36	26	26
20	29	29	1	26	30	30	10	10	2	2
21	8	8	5	1	35	19	16	16	4	9
22	7	6	38	5	19	35	24	15	9	4
23	6	7	26	38	28	28	15	24	69	69
24	20	20	12	12	23	23	32	32	28	18
25	19	19	21	21	39	39	7	7	18	51
26	9	9	19	19	20	20	6	6	51	28
27	31	31	39	29	22	25	38	38	39	39
28	4	4	29	37	17	22	35	18	37	37
29	16	16	37	39	25	17	18	35	64	64
30	28	28	6	6	12	12	31	29	24	24

Sample Data Table Showing Results for I = 7%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	15	4	4	38	38	1	1	34	34
6	26	26	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	9	33	33
8	24	24	34	34	13	26	34	34	6	6
9	27	27	13	13	26	13	3	3	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	32	8	8	11	11	4	4	41	41
13	32	2	10	10	40	40	28	28	31	31
14	10	10	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	5	22	22
16	12	12	32	32	7	24	5	30	77	77
17	13	13	33	33	24	7	8	33	73	55
18	17	17	20	20	27	27	33	8	55	73
19	23	23	7	7	41	41	36	36	26	26
20	29	29	1	1	30	30	10	10	2	2
21	8	8	5	5	35	35	16	16	4	9
22	7	7	38	26	19	19	24	24	9	4
23	6	6	26	38	28	28	15	15	69	69
24	20	20	12	12	23	23	32	32	28	28
25	19	19	21	21	39	39	7	7	18	18
26	9	9	19	19	20	20	6	6	51	51
27	31	31	39	29	22	22	38	38	39	39
28	4	4	29	37	17	25	35	35	37	37
29	16	16	37	39	25	17	18	18	64	64
30	28	28	6	6	12	12	31	31	24	24

Sample Data Table Showing Results for I = 9%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	8	25	25	44	72
4	1	1	31	31	3	3	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	9	29	29
7	22	22	30	30	33	33	9	22	33	33
8	24	24	34	34	13	13	34	3	6	6
9	27	27	13	13	26	26	3	34	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	2	8	8	11	11	4	28	41	41
13	32	10	10	10	40	40	28	4	31	31
14	10	3	14	14	6	6	14	14	5	5
15	3	32	9	32	5	5	30	30	22	22
16	12	12	32	9	7	7	5	8	77	73
17	13	13	33	33	24	24	8	5	73	26
18	17	17	20	20	27	41	33	33	55	77
19	23	23	7	7	41	27	36	36	26	55
20	29	29	1	38	30	30	10	10	2	4
21	8	8	5	1	35	35	16	16	4	2
22	7	7	38	5	19	19	24	24	9	69
23	6	20	26	26	28	28	15	32	69	9
24	20	6	12	12	23	23	32	15	28	28
25	19	19	21	21	39	39	7	7	18	18
26	9	31	19	19	20	20	6	35	51	51
27	31	9	39	39	22	22	38	6	39	39
28	4	4	29	6	17	17	35	38	37	37
29	16	16	37	29	25	12	18	18	64	64
30	28	28	6	37	12	25	31	31	24	38

Sample Data Table Showing Results for I = 10%

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	8	25	25	44	72
4	1	1	31	31	3	3	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	9	29	29
7	22	22	30	30	33	13	9	22	33	33
8	24	24	34	34	13	33	34	3	6	6
9	27	27	13	13	26	26	3	34	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	2	8	10	11	11	4	28	41	41
13	32	10	10	8	40	40	28	4	31	31
14	10	3	14	14	6	6	14	14	5	5
15	3	32	9	32	5	5	30	30	22	22
16	12	12	32	9	7	7	5	8	77	73
17	13	13	33	33	24	24	8	5	73	26
18	17	17	20	20	27	41	33	33	55	77
19	23	23	7	7	41	27	36	36	26	55
20	29	29	1	38	30	30	10	10	2	4
21	8	8	5	1	35	35	16	16	4	69
22	7	7	38	5	19	19	24	24	9	2
23	6	20	26	26	28	20	15	32	69	9
24	20	6	12	21	23	28	32	15	28	28
25	19	19	21	12	39	23	7	7	18	18
26	9	31	19	19	20	39	6	35	51	39
27	31	9	39	39	22	22	38	6	39	51
28	4	4	29	6	17	17	35	18	37	37
29	16	16	37	29	25	12	18	38	64	64
30	28	28	6	37	12	1	31	31	24	38

Sample Data Table Showing Results with Modified CRF - 2

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	2	37	9	27	27	20	20
2	5	11	3	3	9	37	23	25	72	72
3	11	22	2	31	8	3	25	23	44	44
4	1	14	31	15	3	8	21	21	45	29
5	15	27	4	13	38	38	1	1	34	34
6	26	1	15	30	10	10	22	36	29	45
7	22	26	30	25	33	26	9	22	33	30
8	24	5	34	35	13	6	34	28	6	33
9	27	12	13	8	26	41	3	14	68	22
10	30	24	25	34	14	13	19	4	30	6
11	14	15	16	10	31	5	20	30	23	68
12	2	10	8	4	11	24	4	34	41	14
13	32	6	10	26	40	31	28	19	31	7
14	10	2	14	14	6	33	14	5	5	4
15	3	23	9	9	5	14	30	38	22	5
16	12	8	32	20	7	30	5	16	77	41
17	13	17	33	1	24	20	8	24	73	23
18	17	29	20	33	27	11	33	15	55	26
19	23	20	7	16	41	12	36	6	26	9
20	29	32	1	38	30	40	10	31	2	28
21	8	25	5	12	35	15	16	13	4	55
22	7	7	38	21	19	1	24	18	9	73
23	6	3	26	19	28	35	15	20	69	38
24	20	30	12	6	23	29	32	35	28	39
25	19	13	21	32	39	23	7	33	18	2
26	9	9	19	5	20	22	6	2	51	76
27	31	18	39	22	22	39	38	29	39	77
28	4	4	29	37	17	28	35	37	37	25
29	16	28	37	39	25	19	18	26	64	15
30	28	19	6	36	12	36	31	32	24	69

Sample Data Table Showing Results with Modified CRF - 3

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	30	35	35	37	37	27	27	20	20
2	5	21	3	3	9	9	23	25	72	72
3	11	26	2	2	8	8	25	30	44	45
4	1	19	31	4	3	38	21	3	45	33
5	15	11	4	15	38	3	1	21	34	44
6	26	15	15	31	10	33	22	33	29	31
7	22	22	30	30	33	14	9	9	33	6
8	24	24	34	34	13	13	34	22	6	29
9	27	27	13	8	26	40	3	14	68	41
10	30	29	25	25	14	11	19	1	30	18
11	14	14	16	32	31	26	20	8	23	23
12	2	13	8	13	11	10	4	5	41	77
13	32	1	10	26	40	24	28	4	31	5
14	10	7	14	16	6	27	14	10	5	28
15	3	5	9	9	5	7	30	7	22	22
16	12	23	32	5	7	5	5	34	77	55
17	13	20	33	33	24	28	8	36	73	14
18	17	9	20	20	27	1	33	38	55	37
19	23	2	7	1	41	41	36	28	26	30
20	29	10	1	38	30	22	10	6	2	34
21	8	32	5	39	35	17	16	19	4	2
22	7	28	38	29	19	16	24	31	9	9
23	6	4	26	18	28	15	15	12	69	73
24	20	8	12	37	23	29	32	35	28	52
25	19	31	21	14	39	23	7	29	18	51
26	9	6	19	28	20	36	6	15	51	68
27	31	25	39	11	22	30	38	18	39	64
28	4	3	29	12	17	19	35	26	37	25
29	16	18	37	36	25	6	18	37	64	71
30	28	16	6	17	12	4	31	11	24	69

Sample Data Table Showing Results with Modified CRF - 4

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	44
2	5	1	3	3	9	3	23	23	72	20
3	11	26	2	2	8	38	25	25	44	72
4	1	22	31	4	3	9	21	21	45	29
5	15	12	4	31	38	10	1	20	34	45
6	26	5	15	10	10	8	22	9	29	34
7	22	3	30	34	33	26	9	1	33	33
8	24	2	34	15	13	13	34	22	6	18
9	27	14	13	30	26	40	3	19	68	51
10	30	10	25	14	14	35	19	28	30	68
11	14	11	16	13	31	11	20	4	23	31
12	2	32	8	33	11	5	4	3	41	73
13	32	23	10	25	40	30	28	14	31	6
14	10	30	14	9	6	24	14	8	5	30
15	3	27	9	20	5	6	30	16	22	39
16	12	31	32	8	7	7	5	15	77	37
17	13	24	33	38	24	31	8	5	73	38
18	17	15	20	29	27	12	33	34	55	69
19	23	6	7	39	41	17	36	32	26	2
20	29	13	1	12	30	22	10	35	2	55
21	8	7	5	36	35	1	16	6	4	5
22	7	20	38	32	19	18	24	29	9	28
23	6	9	26	16	28	25	15	37	69	9
24	20	17	12	5	23	19	32	2	28	7
25	19	19	21	28	39	16	7	10	18	58
26	9	16	19	1	20	27	6	31	51	43
27	31	18	39	22	22	28	38	33	39	60
28	4	28	29	7	17	33	35	24	37	71
29	16	25	37	23	25	4	18	26	64	22
30	28	29	6	24	12	15	31	18	24	64

Sample Data Table Showing Results with Modified CRF - 5

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	3	37	37	27	27	20	20
2	5	5	3	2	9	9	23	23	72	44
3	11	11	2	35	8	8	25	25	44	45
4	1	26	31	4	3	38	21	3	45	72
5	15	12	4	10	38	10	1	1	34	68
6	26	24	15	15	10	3	22	21	29	41
7	22	30	30	34	33	13	9	10	33	33
8	24	15	34	30	13	14	34	22	6	14
9	27	27	13	31	26	40	3	5	68	34
10	30	1	25	25	14	26	19	14	30	7
11	14	32	16	33	31	33	20	8	23	5
12	2	8	8	14	11	11	4	19	41	6
13	32	31	10	7	40	1	28	38	31	31
14	10	10	14	32	6	5	14	36	5	4
15	3	22	9	9	5	6	30	13	22	22
16	12	2	32	13	7	41	5	30	77	2
17	13	3	33	26	24	19	8	28	73	73
18	17	19	20	16	27	35	33	4	55	23
19	23	13	7	5	41	25	36	35	26	55
20	29	6	1	20	30	27	10	6	2	69
21	8	29	5	21	35	16	16	24	4	28
22	7	23	38	8	19	22	24	7	9	26
23	6	9	26	39	28	23	15	34	69	9
24	20	14	12	19	23	28	32	32	28	60
25	19	16	21	1	39	30	7	9	18	52
26	9	28	19	28	20	12	6	15	51	39
27	31	7	39	38	22	39	38	37	39	30
28	4	25	29	12	17	4	35	18	37	24
29	16	20	37	24	25	21	18	33	64	77
30	28	4	6	37	12	18	31	31	24	71

Sample Data Table Showing Results for Accident Rate = Accident Rate - 0.2

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	4	3	3	21	21	45	45
5	15	26	4	31	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	27	34	34	13	13	34	34	6	6
9	27	24	13	13	26	26	3	3	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	2	8	8	11	11	4	4	41	41
13	32	32	10	10	40	40	28	28	31	31
14	10	10	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	7	5	5	77	77
17	13	13	33	33	24	24	8	8	73	73
18	17	17	20	20	27	27	33	33	55	55
19	23	29	7	7	41	41	36	36	26	26
20	29	23	1	1	30	30	10	10	2	2
21	8	8	5	5	35	35	16	16	4	4
22	7	7	38	38	19	19	24	24	9	9
23	6	6	26	26	28	28	15	15	69	69
24	20	20	12	12	23	23	32	32	28	28
25	19	19	21	21	39	39	7	7	18	18
26	9	9	19	19	20	20	6	6	51	51
27	31	31	39	29	22	22	38	38	39	39
28	4	4	29	37	17	25	35	35	37	37
29	16	28	37	39	25	17	18	18	64	64
30	28	16	6	6	12	12	31	31	24	24

Sample Data Table Showing Results for Accident Rate = Accident Rate - 0.3

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	4	3	3	21	21	45	45
5	15	26	4	31	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	27	34	34	13	13	34	34	6	6
9	27	30	13	13	26	26	3	3	68	68
10	30	24	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	20	23	23
12	2	32	8	8	11	11	4	4	41	41
13	32	2	10	10	40	40	28	28	31	31
14	10	10	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	24	5	5	77	77
17	13	13	33	33	24	7	8	8	73	73
18	17	17	20	20	27	27	33	33	55	55
19	23	29	7	7	41	41	36	36	26	26
20	29	23	1	1	30	30	10	10	2	2
21	8	8	5	5	35	35	16	16	4	4
22	7	7	38	38	19	19	24	15	9	9
23	6	6	26	26	28	28	15	24	69	69
24	20	20	12	12	23	23	32	32	28	28
25	19	19	21	21	39	39	7	7	18	18
26	9	9	19	19	20	20	6	6	51	51
27	31	31	39	29	22	25	38	38	39	39
28	4	4	29	37	17	22	35	35	37	37
29	16	28	37	39	25	17	18	18	64	64
30	28	16	6	6	12	12	31	31	24	24

Sample Data Table Showing Results for Accident Rate = Accident Rate + 0.1

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	21	72	72
3	11	11	2	2	8	8	25	19	44	44
4	1	1	31	31	3	3	21	23	45	45
5	15	15	4	4	38	38	1	14	34	34
6	26	26	15	15	10	10	22	15	29	29
7	22	22	30	30	33	33	9	18	33	68
8	24	24	34	34	13	13	34	33	6	33
9	27	27	13	13	26	26	3	22	68	5
10	30	30	25	25	14	14	19	3	30	6
11	14	14	16	16	31	31	20	25	23	30
12	2	2	8	8	11	11	4	9	41	23
13	32	10	10	10	40	40	28	1	31	41
14	10	32	14	14	6	6	14	10	5	31
15	3	3	9	9	5	5	30	28	22	69
16	12	12	32	32	7	7	5	13	77	64
17	13	13	33	33	24	24	8	34	73	26
18	17	17	20	20	27	27	33	8	55	73
19	23	23	7	7	41	41	36	20	26	22
20	29	29	1	26	30	30	10	30	2	28
21	8	8	5	1	35	35	16	4	4	77
22	7	7	38	5	19	19	24	36	9	55
23	6	6	26	38	28	28	15	7	69	2
24	20	20	12	12	23	23	32	5	28	4
25	19	19	21	21	39	39	7	29	18	9
26	9	25	19	17	20	20	6	37	51	39
27	31	9	39	39	22	22	38	16	39	18
28	4	31	29	19	17	17	35	32	37	51
29	16	4	37	6	25	25	18	24	64	37
30	28	16	6	29	12	12	31	17	24	43

Sample Data Table Showing Results for Accident Rate = Accident Rate + 0.2

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	21	72	72
3	11	11	2	2	8	8	25	19	44	44
4	1	1	31	31	3	3	21	18	45	5
5	15	15	4	4	38	38	1	15	34	45
6	26	26	15	30	10	10	22	33	29	68
7	22	22	30	15	33	33	9	14	33	34
8	24	24	34	34	13	13	34	3	6	29
9	27	27	13	13	26	26	3	22	68	33
10	30	30	25	25	14	14	19	23	30	6
11	14	14	16	16	31	31	20	10	23	64
12	2	2	8	8	11	11	4	13	41	69
13	32	10	10	10	40	40	28	25	31	30
14	10	32	14	14	6	6	14	9	5	23
15	3	3	9	9	5	5	30	28	22	26
16	12	12	32	32	7	7	5	1	77	41
17	13	13	33	33	24	24	8	34	73	31
18	17	17	20	20	27	27	33	8	55	73
19	23	23	7	7	41	41	36	30	26	28
20	29	29	1	26	30	30	10	29	2	22
21	8	8	5	1	35	35	16	37	4	77
22	7	7	38	5	19	19	24	7	9	55
23	6	6	26	38	28	28	15	20	69	39
24	20	25	12	12	23	23	32	4	28	4
25	19	20	21	21	39	39	7	17	18	2
26	9	19	19	17	20	15	6	36	51	9
27	31	9	39	39	22	20	38	16	39	18
28	4	31	29	19	17	22	35	5	37	43
29	16	4	37	6	25	17	18	32	64	51
30	28	16	6	29	12	12	31	31	24	50

Sample Data Table Showing Results for Accident Rate = Accident Rate + 0.3

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	19	72	72
3	11	11	2	2	8	8	25	21	44	44
4	1	1	31	31	3	3	21	18	45	5
5	15	15	4	4	38	38	1	15	34	68
6	26	26	15	30	10	10	22	33	29	45
7	22	22	30	15	33	33	9	14	33	34
8	24	24	34	34	13	13	34	3	6	29
9	27	27	13	13	26	26	3	10	68	33
10	30	30	25	25	14	14	19	22	30	6
11	14	14	16	16	31	31	20	13	23	64
12	2	2	8	8	11	11	4	23	41	69
13	32	10	10	10	40	40	28	9	31	30
14	10	32	14	14	6	6	14	28	5	26
15	3	3	9	9	5	5	30	25	22	23
16	12	12	32	32	7	7	5	1	77	73
17	13	13	33	33	24	24	8	8	73	28
18	17	17	20	20	27	27	33	29	55	41
19	23	23	7	7	41	41	36	37	26	31
20	29	29	1	26	30	30	10	30	2	22
21	8	8	5	1	35	35	16	17	4	77
22	7	25	38	5	19	19	24	7	9	55
23	6	7	26	38	28	15	15	34	69	39
24	20	6	12	17	23	28	32	36	28	50
25	19	20	21	12	39	23	7	20	18	43
26	9	19	19	21	20	39	6	4	51	4
27	31	9	39	39	22	20	38	16	39	2
28	4	31	29	19	17	22	35	32	37	59
29	16	4	37	6	25	17	18	31	64	9
30	28	16	6	29	12	12	31	5	24	25

Sample Data Table Showing Results for Crash Flow Relationship = $A^{0.6}$

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	3	25	25	44	72
4	1	1	31	31	3	8	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	27	34	34	13	13	34	3	6	6
9	27	24	13	13	26	26	3	34	68	68
10	30	14	25	25	14	14	19	19	30	30
11	14	30	16	16	31	31	20	4	23	23
12	2	2	8	8	11	11	4	28	41	31
13	32	10	10	10	40	40	28	20	31	41
14	10	3	14	14	6	6	14	14	5	5
15	3	32	9	9	5	5	30	30	22	22
16	12	12	32	32	7	24	5	5	77	73
17	13	13	33	33	24	7	8	8	73	77
18	17	17	20	20	27	41	33	33	55	26
19	23	23	7	7	41	27	36	36	26	2
20	29	29	1	38	30	30	10	10	2	9
21	8	8	5	1	35	35	16	16	4	55
22	7	7	38	5	19	19	24	24	9	4
23	6	20	26	26	28	28	15	15	69	69
24	20	6	12	12	23	39	32	32	28	28
25	19	19	21	21	39	23	7	7	18	51
26	9	31	19	19	20	20	6	35	51	18
27	31	9	39	39	22	22	38	18	39	39
28	4	4	29	29	17	17	35	6	37	37
29	16	28	37	37	25	25	18	38	64	64
30	28	16	6	6	12	1	31	31	24	24

Sample Data Table Showing Results for Crash Flow Relationship = $A^{0.7}$

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	3	25	25	44	72
4	1	1	31	31	3	8	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	27	34	34	13	13	34	3	6	6
9	27	24	13	13	26	26	3	34	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	4	23	23
12	2	2	8	8	11	11	4	28	41	41
13	32	10	10	10	40	40	28	20	31	31
14	10	32	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	24	5	5	77	73
17	13	13	33	33	24	7	8	8	73	77
18	17	17	20	20	27	41	33	33	55	26
19	23	23	7	7	41	27	36	36	26	55
20	29	29	1	38	30	30	10	10	2	2
21	8	8	5	1	35	35	16	16	4	9
22	7	7	38	5	19	19	24	24	9	4
23	6	20	26	26	28	28	15	15	69	69
24	20	6	12	12	23	39	32	32	28	28
25	19	19	21	21	39	23	7	7	18	18
26	9	31	19	19	20	20	6	35	51	51
27	31	9	39	39	22	22	38	6	39	39
28	4	4	29	29	17	17	35	18	37	37
29	16	28	37	37	25	25	18	38	64	64
30	28	16	6	6	12	12	31	31	24	24

Sample Data Table Showing Results for Crash Flow Relationship = $A^{0.8}$

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	44
3	11	11	2	2	8	8	25	25	44	72
4	1	1	31	4	3	3	21	21	45	45
5	15	26	4	31	38	38	1	1	34	34
6	26	15	15	30	10	10	22	22	29	29
7	22	22	30	15	33	33	9	9	33	33
8	24	24	34	34	13	13	34	3	6	6
9	27	27	13	13	26	26	3	34	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	4	23	23
12	2	2	8	10	11	11	4	20	41	41
13	32	10	10	8	40	40	28	28	31	31
14	10	32	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	24	5	5	77	73
17	13	13	33	33	24	7	8	8	73	77
18	17	17	20	7	27	41	33	33	55	26
19	23	23	7	38	41	27	36	36	26	55
20	29	29	1	20	30	30	10	10	2	2
21	8	8	5	5	35	35	16	16	4	4
22	7	7	38	26	19	19	24	24	9	9
23	6	20	26	1	28	28	15	15	69	69
24	20	6	12	21	23	39	32	32	28	28
25	19	19	21	12	39	23	7	7	18	18
26	9	31	19	39	20	20	6	35	51	51
27	31	9	39	19	22	22	38	6	39	39
28	4	4	29	29	17	17	35	18	37	37
29	16	28	37	37	25	25	18	38	64	64
30	28	16	6	6	12	12	31	31	24	24

Sample Data Table Showing Results for Crash Flow Relationship = $A^{0.9}$

Program Year	1998		1996		1995		1994		1992	
Rank	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
1	21	21	35	35	37	37	27	27	20	20
2	5	5	3	3	9	9	23	23	72	72
3	11	11	2	2	8	8	25	25	44	44
4	1	1	31	31	3	3	21	21	45	45
5	15	26	4	4	38	38	1	1	34	34
6	26	15	15	15	10	10	22	22	29	29
7	22	22	30	30	33	33	9	9	33	33
8	24	24	34	34	13	13	34	34	6	6
9	27	27	13	13	26	26	3	3	68	68
10	30	30	25	25	14	14	19	19	30	30
11	14	14	16	16	31	31	20	4	23	23
12	2	2	8	8	11	11	4	20	41	41
13	32	10	10	10	40	40	28	28	31	31
14	10	32	14	14	6	6	14	14	5	5
15	3	3	9	9	5	5	30	30	22	22
16	12	12	32	32	7	7	5	5	77	77
17	13	13	33	33	24	24	8	8	73	73
18	17	17	20	20	27	41	33	33	55	26
19	23	23	7	7	41	27	36	36	26	55
20	29	29	1	38	30	30	10	10	2	2
21	8	8	5	1	35	35	16	16	4	4
22	7	7	38	5	19	19	24	24	9	9
23	6	6	26	26	28	28	15	15	69	69
24	20	20	12	12	23	39	32	32	28	28
25	19	19	21	21	39	23	7	7	18	18
26	9	31	19	19	20	20	6	6	51	51
27	31	9	39	39	22	22	38	35	39	39
28	4	4	29	29	17	17	35	38	37	37
29	16	16	37	37	25	25	18	18	64	64
30	28	28	6	6	12	12	31	31	24	24

APPENDIX B

STATISTICAL TESTS: RESULTS

Sample Data Table Showing Statistical Inferences for I = 3%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	10	sum(d2)	134	sum(d2)	242	sum(d2)	138	sum(d2)	906
	ρ	0.9982	ρ	0.9874	ρ	0.9789	ρ	0.9849	ρ	0.9890
	z-value	5.5576	z-value	6.1665	z-value	6.1912	z-value	5.9909	z-value	8.7344
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.984	τ	0.936	τ	0.912	τ	0.915	τ	0.927
	(τ+1)/2	0.992	(τ+1)/2	0.968	(τ+1)/2	0.956	(τ+1)/2	0.957	(τ+1)/2	0.963625
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	39	No. of pairs retaining rank	36	No. of pairs retaining rank	76
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	2	No. of pairs showing change	2	No. of pairs showing change	3

Sample Data Table Showing Statistical Inferences for I = 4%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	4	sum(d2)	92	sum(d2)	156	sum(d2)	70	sum(d2)	628
	ρ	0.9993	ρ	0.9914	ρ	0.9864	ρ	0.9923	ρ	0.9924
	z-value	5.5637	z-value	6.1911	z-value	6.2386	z-value	6.0362	z-value	8.7643
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.992	τ	0.956	τ	0.934	τ	0.943	τ	0.940
	(τ+1)/2	0.996	(τ+1)/2	0.978	(τ+1)/2	0.967	(τ+1)/2	0.972	(τ+1)/2	0.969795
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	40	No. of pairs retaining rank	37	No. of pairs retaining rank	77
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	2

Sample Data Table Showing Statistical Inferences for I = 5%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	4	sum(d2)	44	sum(d2)	76	sum(d2)	48	sum(d2)	326
	ρ	0.9993	ρ	0.9959	ρ	0.9934	ρ	0.9947	ρ	0.9960
	z-value	5.5637	z-value	6.2192	z-value	6.2827	z-value	6.0508	z-value	8.7967
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.059	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.992	τ	0.969	τ	0.954	τ	0.954	τ	0.958
	(τ+1)/2	0.996	(τ+1)/2	0.985	(τ+1)/2	0.977	(τ+1)/2	0.977	(τ+1)/2	0.97889
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	40	No. of pairs retaining rank	37	No. of pairs retaining rank	77
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	2

Sample Data Table Showing Statistical Inferences for I = 6%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	4	sum(d2)	26	sum(d2)	56	sum(d2)	24	sum(d2)	152
	ρ	0.9993	ρ	0.9976	ρ	0.9951	ρ	0.9974	ρ	0.9981
	z-value	5.5637	z-value	6.2298	z-value	6.2937	z-value	6.0668	z-value	8.8154
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.992	τ	0.979	τ	0.961	τ	0.974	τ	0.975
	(τ+1)/2	0.996	(τ+1)/2	0.990	(τ+1)/2	0.980	(τ+1)/2	0.987	(τ+1)/2	0.987335
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	40	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	1

Sample Data Table Showing Statistical Inferences for I = 7%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	2	sum(d2)	16	sum(d2)	18	sum(d2)	4	sum(d2)	55
	ρ	0.9996	ρ	0.9985	ρ	0.9984	ρ	0.9996	ρ	0.9993
	z-value	5.5657	z-value	6.2356	z-value	6.3146	z-value	6.0801	z-value	8.8258
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.996	τ	0.985	τ	0.985	τ	0.994	τ	0.989
	(τ+1)/2	0.998	(τ+1)/2	0.992	(τ+1)/2	0.993	(τ+1)/2	0.997	(τ+1)/2	0.9944
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

Sample Data Table Showing Statistical Inferences for I = 9%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	12	sum(d2)	16	sum(d2)	14	sum(d2)	16	sum(d2)	68
	ρ	0.9978	ρ	0.9985	ρ	0.9988	ρ	0.9982	ρ	0.9992
	z-value	5.5555	z-value	6.2356	z-value	6.3168	z-value	6.0721	z-value	8.8245
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.980	τ	0.985	τ	0.988	τ	0.980	τ	0.984
	(τ+1)/2	0.990	(τ+1)/2	0.992	(τ+1)/2	0.994	(τ+1)/2	0.990	(τ+1)/2	0.992205
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	1

Sample Data Table Showing Statistical Inferences for I = 10%

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	12	sum(d2)	22	sum(d2)	40	sum(d2)	20	sum(d2)	130
	ρ	0.9978	ρ	0.9979	ρ	0.9965	ρ	0.9978	ρ	0.9984
	z-value	5.5555	z-value	6.2321	z-value	6.3025	z-value	6.0695	z-value	8.8178
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.980	τ	0.977	τ	0.971	τ	0.977	τ	0.977
	(τ+1)/2	0.990	(τ+1)/2	0.988	(τ+1)/2	0.985	(τ+1)/2	0.989	(τ+1)/2	0.98831
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	40	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	1

Sample Data Table Showing Statistical Inferences for Modified CRF 2

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	944	sum(d2)	990	sum(d2)	2320	sum(d2)	3591	sum(d2)	21046
	ρ	0.8270	ρ	0.9071	ρ	0.7979	ρ	0.6071	ρ	0.7438
	z-value	4.6044	z-value	5.6650	z-value	5.0464	z-value	3.6927	z-value	6.5694
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0002	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.625	τ	0.755	τ	0.622	τ	0.504	τ	0.568
	(τ+1)/2	0.813	(τ+1)/2	0.877	(τ+1)/2	0.811	(τ+1)/2	0.752	(τ+1)/2	0.78393
	No. of pairs retaining rank	26	No. of pairs retaining rank	35	No. of pairs retaining rank	33	No. of pairs retaining rank	29	No. of pairs retaining rank	62
	No. of pairs showing change	6	No. of pairs showing change	5	No. of pairs showing change	8	No. of pairs showing change	9	No. of pairs showing change	17

Sample Data Table Showing Statistical Inferences for Modified CRF 3

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	1974	sum(d2)	1944	sum(d2)	2292	sum(d2)	3727	sum(d2)	19670
	ρ	0.6382	ρ	0.8176	ρ	0.8003	ρ	0.5922	ρ	0.7606
	z-value	3.5533	z-value	5.1061	z-value	5.0618	z-value	3.6021	z-value	6.7173
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0004	p value	0.0001	p value	0.0001	p value	0.0003	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.480	τ	0.683	τ	0.644	τ	0.461	τ	0.609
	(τ+1)/2	0.740	(τ+1)/2	0.841	(τ+1)/2	0.822	(τ+1)/2	0.731	(τ+1)/2	0.80471
	No. of pairs retaining rank	24	No. of pairs retaining rank	34	No. of pairs retaining rank	34	No. of pairs retaining rank	28	No. of pairs retaining rank	64
	No. of pairs showing change	8	No. of pairs showing change	6	No. of pairs showing change	7	No. of pairs showing change	10	No. of pairs showing change	15

Sample Data Table Showing Statistical Inferences for Modified CRF 4

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	1130	sum(d2)	1796	sum(d2)	3210	sum(d2)	1827	sum(d2)	22230
	ρ	0.7929	ρ	0.8315	ρ	0.7204	ρ	0.8001	ρ	0.7294
	z-value	4.4146	z-value	5.1928	z-value	4.5561	z-value	4.8667	z-value	6.4422
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.581	τ	0.650	τ	0.566	τ	0.646	τ	0.563
	(τ+1)/2	0.790	(τ+1)/2	0.825	(τ+1)/2	0.783	(τ+1)/2	0.823	(τ+1)/2	0.781655
	No. of pairs retaining rank	25	No. of pairs retaining rank	33	No. of pairs retaining rank	32	No. of pairs retaining rank	31	No. of pairs retaining rank	62
	No. of pairs showing change	7	No. of pairs showing change	7	No. of pairs showing change	9	No. of pairs showing change	7	No. of pairs showing change	17

Sample Data Table Showing Statistical Inferences for Modified CRF 5

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	1090	sum(d2)	1038	sum(d2)	3152	sum(d2)	2495	sum(d2)	25974
	ρ	0.8002	ρ	0.9026	ρ	0.7254	ρ	0.7270	ρ	0.6839
	z-value	4.4554	z-value	5.6369	z-value	4.5881	z-value	4.4221	z-value	6.0397
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.629	τ	0.729	τ	0.593	τ	0.549	τ	0.531
	(τ+1)/2	0.815	(τ+1)/2	0.865	(τ+1)/2	0.796	(τ+1)/2	0.775	(τ+1)/2	0.76542
	No. of pairs retaining rank	26	No. of pairs retaining rank	35	No. of pairs retaining rank	33	No. of pairs retaining rank	29	No. of pairs retaining rank	60
	No. of pairs showing change	6	No. of pairs showing change	5	No. of pairs showing change	8	No. of pairs showing change	9	No. of pairs showing change	19

Sample Data Table Showing Statistical Inferences for Mean = Mean - 0.1

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	6	sum(d2)	11	sum(d2)		sum(d2)		sum(d2)	
	ρ	0.9989	ρ	0.9990	ρ		ρ		ρ	
	z-value	5.5616	z-value	6.2386	z-value		z-value		z-value	
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation		Correlation		Correlation	
	p value	0.0001	p value	0.0001	p value		p value		p value	
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0							
Kendall's	τ	0.988	τ	0.989	τ	1.000	τ	1.000	τ	1.000
	(τ+1)/2	0.994	(τ+1)/2	0.995	(τ+1)/2	1.000	(τ+1)/2	1.000	(τ+1)/2	1
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

Sample Data Table Showing Statistical Inferences for Mean = Mean - 0.3

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	14	sum(d2)	12	sum(d2)	26	sum(d2)	4	sum(d2)	4
	ρ	0.9974	ρ	0.9989	ρ	0.9977	ρ	0.9996	ρ	1.0000
	z-value	5.5535	z-value	6.2380	z-value	6.3102	z-value	6.0801	z-value	8.8313
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.976	τ	0.987	τ	0.980	τ	0.994	τ	0.999
	(τ+1)/2	0.988	(τ+1)/2	0.994	(τ+1)/2	0.990	(τ+1)/2	0.997	(τ+1)/2	0.99935
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

Sample Data Table Showing Statistical Inferences for Mean = Mean + 0.1

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	32	sum(d2)	64	sum(d2)	48	sum(d2)	2178	sum(d2)	3934
	ρ	0.9941	ρ	0.9940	ρ	0.9958	ρ	0.7617	ρ	0.9521
	z-value	5.5351	z-value	6.2075	z-value	6.2981	z-value	4.6331	z-value	8.4089
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.976	τ	0.967	τ	0.980	τ	0.593	τ	0.836
	(τ+1)/2	0.988	(τ+1)/2	0.983	(τ+1)/2	0.990	(τ+1)/2	0.796	(τ+1)/2	0.91783
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	41	No. of pairs retaining rank	30	No. of pairs retaining rank	73
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	8	No. of pairs showing change	6

Sample Data Table Showing Statistical Inferences for Mean = Mean + 0.2

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	58	sum(d2)	66	sum(d2)	172	sum(d2)	3394	sum(d2)	7710
	ρ	0.9894	ρ	0.9938	ρ	0.9850	ρ	0.6286	ρ	0.9062
	z-value	5.5086	z-value	6.2063	z-value	6.2298	z-value	3.8238	z-value	8.0030
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.968	τ	0.964	τ	0.956	τ	0.462	τ	0.747
	(τ+1)/2	0.984	(τ+1)/2	0.982	(τ+1)/2	0.978	(τ+1)/2	0.731	(τ+1)/2	0.873335
	No. of pairs retaining rank	31	No. of pairs retaining rank	39	No. of pairs retaining rank	40	No. of pairs retaining rank	28	No. of pairs retaining rank	69
	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	10	No. of pairs showing change	10

Sample Data Table Showing Statistical Inferences for Mean = Mean + 0.3

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	92	sum(d2)	96	sum(d2)	266	sum(d2)	4128	sum(d2)	11410
	ρ	0.9831	ρ	0.9910	ρ	0.9768	ρ	0.5483	ρ	0.8611
	z-value	5.4739	z-value	6.1888	z-value	6.1780	z-value	3.3352	z-value	7.6052
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0009	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.960	τ	0.959	τ	0.944	τ	0.390	τ	0.692
	(τ+1)/2	0.980	(τ+1)/2	0.979	(τ+1)/2	0.972	(τ+1)/2	0.695	(τ+1)/2	0.846055
	No. of pairs retaining rank	31	No. of pairs retaining rank	39	No. of pairs retaining rank	40	No. of pairs retaining rank	26	No. of pairs retaining rank	67
	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	1	No. of pairs showing change	12	No. of pairs showing change	12

Sample Data Table Showing statistical Inferences for Crash Flow Relationship - $A^{0.6}$

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	18	sum(d2)	14	sum(d2)	20	sum(d2)	24	sum(d2)	136
	ρ	0.9967	ρ	0.9987	ρ	0.9983	ρ	0.9974	ρ	0.9983
	z-value	5.5494	z-value	6.2368	z-value	6.3135	z-value	6.0668	z-value	8.8171
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.968	τ	0.987	τ	0.980	τ	0.980	τ	0.973
	(τ+1)/2	0.984	(τ+1)/2	0.994	(τ+1)/2	0.990	(τ+1)/2	0.990	(τ+1)/2	0.986685
	No. of pairs retaining rank	31	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	1

Sample Data Table Showing statistical Inferences for Crash Flow Relationship - $A^{0.7}$

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	12	sum(d2)	14	sum(d2)	18	sum(d2)	18	sum(d2)	66
	ρ	0.9978	ρ	0.9987	ρ	0.9984	ρ	0.9980	ρ	0.9992
	z-value	5.5555	z-value	6.2368	z-value	6.3146	z-value	6.0708	z-value	8.8247
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.976	τ	0.987	τ	0.983	τ	0.983	τ	0.984
	(τ+1)/2	0.988	(τ+1)/2	0.994	(τ+1)/2	0.991	(τ+1)/2	0.991	(τ+1)/2	0.99188
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	78
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	1

Sample Data Table Showing statistical Inferences for Crash Flow Relationship - $A^{0.8}$

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	10	sum(d2)	57	sum(d2)	12	sum(d2)	14	sum(d2)	48
	ρ	0.9982	ρ	0.9947	ρ	0.9990	ρ	0.9985	ρ	0.9994
	z-value	5.5576	z-value	6.2116	z-value	6.3179	z-value	6.0734	z-value	8.8266
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.980	τ	0.961	τ	0.988	τ	0.986	τ	0.988
	(τ+1)/2	0.990	(τ+1)/2	0.980	(τ+1)/2	0.994	(τ+1)/2	0.993	(τ+1)/2	0.994155
	No. of pairs retaining rank	32	No. of pairs retaining rank	39	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	1	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

Sample Data Table Showing statistical Inferences for Crash Flow Relationship - $A^{0.9}$

Test	1998		1996		1995		1994		1992	
Spearman	sum(d2)	6	sum(d2)	8	sum(d2)	6	sum(d2)	4	sum(d2)	23
	ρ	0.9989	ρ	0.9992	ρ	0.9995	ρ	0.9996	ρ	0.9997
	z-value	5.5616	z-value	6.2403	z-value	6.3212	z-value	6.0801	z-value	8.8293
	>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)		>1.96(z-crit)	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001	p value	0.0001
	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05	p critical	0.05
	p < p critical		p < p critical		p < p critical		p < p critical		p < p critical	
	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes	Correlation	yes
	h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation		h0 = no correlation	
	reject h0		reject h0		reject h0		reject h0		reject h0	
Kendall's	τ	0.988	τ	0.992	τ	0.993	τ	0.994	τ	0.994
	(τ+1)/2	0.994	(τ+1)/2	0.996	(τ+1)/2	0.996	(τ+1)/2	0.997	(τ+1)/2	0.996995
	No. of pairs retaining rank	32	No. of pairs retaining rank	40	No. of pairs retaining rank	41	No. of pairs retaining rank	38	No. of pairs retaining rank	79
	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0	No. of pairs showing change	0

APPENDIX C

HAZARD ELIMINATION PROGRAM (HES): WORK CODES

Work Codes

Code	Item
100	Signing and Signals
200	Roadside Obstacles and Barriers
300	Resurfacing and Roadway Lighting
400	Pavement Markings
500	Roadway Work

Signing and Signals

Work Code	Description	Definition	Reduction Factor %	Preventable Accident
101	Install Warning/Guide Signs	Provide advance signing for unusual or unexpected roadway features where no signing existed previously.	20	(Vehicle Movements/Manner of Collision = 20-22 or 30) OR (Roadway Related = 2 or 3)
102	Install STOP Signs	Provide STOP signs where none existed previously.	20	Intersection Related = 1 or 2
103	Install Advance Warning Signals	Provide flasher units, where none existed previously in advance of the identified problem area.	To be defined.	Will be determined from supplied diagram
104	Improve Advance Warning Signals	Bring existing flasher units into conformance with current design standards. Refer to W.C. 106 for modernization of intersection flashing beacons.	To be defined.	Will be determined from supplied diagram
105	Install Intersection Flashing Beacon	Provide a flashing beacon at an intersection where a beacon did not exit previously.	50	Intersection Related = 1 or 2
106	Modernize Intersection Flashing Beacon	Improve an existing flashing beacon, located at an intersection, to current design standards. Refer to W.C. 104 for non-intersection flashing beacon.	10	Intersection Related = 1 or 2
107	Install Traffic Signal	Provide a traffic signal where none existed previously.	28	[(Intersection Related = 1 or 2) AND (Vehicle Movements/Manner of Collision = 10-39)] OR (First Harmful Event = 1 or 5)
108	Improve Traffic Signals	Modernize existing intersection signals to current design standards. Refer to W.C. 106 for modernization of intersection flashing beacons.	22	[(Intersection Related = 1 or 2) AND (Vehicle Movements/Manner of Collision = 10-39)] OR (First Harmful Event = 1 or 5)
109	Add Left Turn Signal Phase	Provide a left turn signal phase at an existing signalized intersection with existing left turn lanes. Affected intersection approaches must be specified.	25	Vehicle Movements/Manner of Collision = 34 or 36
110	Install Pedestrian Signal	Provide a pedestrian signal at an existing signalized location where no pedestrian phase exists, but pedestrian crosswalks existing. Refer to W.C. 403 for installation of pedestrian crosswalks.	15	First Harmful Event = 1
111	Interconnect Signals	Provide a communication link between two or more adjacent	10	All

		signals in a corridor. Specify all signalized intersections to be included in the interconnection.		
112	Overheight Warning System	Install electronic devices to detect overheight loads.	65	Object Struck = 43
113	Install Delineators	Install post-mounted delineators to provide guidance.	30	(Roadway Related = 2 or 3) AND (Light Condition = 3 or 4)
114	Install School Zones	Place school zones to include signing and/or pavement marking where none existed previously. Refer to W.C. 403 for pedestrian crosswalk markings.	20	All
115	Eliminate Parking with Milepoints	Completely remove existing parking on one side of the roadway in the direction of the milepoints.	32	(First Harmful Event = 1 or 4 OR (Vehicle Movements/Manner of Collision = 40-44 OR [(Vehicle Movements/Manner of Collision = 10) AND ((Direction of Travel 1 = 1 or 5) AND (Direction of Travel 2 = 2, 3 or 4))] OR [(Vehicle Movements/Manner of Collision = 10) AND ((Direction of Travel 1=2, 3, or 4) AND (Direction of Travel 2=1or 5))}
116	Eliminate Parking Opposite Milepoints	Completely remove existing parking on one side of the roadway in the direction of the milepoints.	32	(First Harmful Event = 1 or 4 OR (Vehicle Movements/Manner of Collision = 40-44 OR [(Vehicle Movements/Manner of Collision = 10) AND ((Direction of Travel 1 = 1 or 5) AND (Direction of Travel 2 = 6, 7, or 8))] OR [(Vehicle Movements/Manner of Collision = 10) AND ((Direction of Travel 1 = 6, 7, or 8) AND (Direction of Travel 2 = 1or 5))}
117	Eliminate Parking	Completely remove existing parking on the roadway.	32	(First Harmful Event = 1 or 4) OR (Vehicle Movements/Manner of Collision = 40-44 or 10)
118	Replace Flashing Beacon with a Traffic Signal	Replace an existing flashing beacon at an intersection with a traffic signal.	25	[(Intersection Related = 1 or 2) AND (Vehicle Movements/Manner of Collision = 10-39) OR (First Harmful Event = 1 or 5
119	Install Overhead Guide Signs	Install overhead advance signing for unusual or unexpected roadway features where no signing existed previously.	20	Vehicle Movement/Manner of Collision = 20-29
121	Convert 2-way STOP Signs to 4-way STOP Signs	Provide 4-way STOP signs where 2-way STOP signs existed previously.	15	Intersection/Intersection Related = 1 or 2
122	Install Advanced Warning Signals (Intersection – Existing Signal, Flashing Beacon to STOP Signs)	Provide flasher units in advance of an intersection where none previously existed.	10	Intersection Related = 1 or 2
123	Install Advanced Warning Signals (Curve)	Provide flasher units in advance of an intersection where none previously existed.	10	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 20-24 or 30)
124	Install Advanced Warning Signals and	Provide flasher units and signs in advance of an intersection where	15	Intersection Related = 1 or 2

	Signs (Intersection – Existing Beacon or STOP Signs)	none previously existed.		
125	Install Advanced Warning Signals	Provide flasher units and signs in advance of a curve where none previously existed.	15	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 20-24 or 30)
126	Install Advanced Warning Signals and/or Signs (Intersection – Uncontrolled, No Existing Advance Warning)	Provide flasher units and/or signs in advance of an uncontrolled intersection where none previously existed.	20	Intersection Related = 1 or 2
127	Install Advanced Warning Signals (Intersection – Existing Warning Signs)	Provide flasher units in advance of an intersection where none previously existed. Advance warning signs already exist.	10	Intersection Related = 1 or 2
128	Install Advanced Warning Signals (Curve - Existing Warning Signals)	Provide signs in advance of an intersection where none previously existed. Advance warning signals already exist.	5	Intersection Related = 1 or 2
129	Install Advanced Warning Signals (Curve – Existing Warning Signs)	Provide flasher units in advance of a curve where none previously existed. Advance warning signs already exist.	10	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 20-24 or 30)
130	Install Advanced Warning Signs (Curve – Existing Warning Signals)	Provide signs in advance of a curve where none previously existed. Advance warning signals already exist.	5	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 20-24 or 30)
131	Improve Pedestrian Signals	Bring existing pedestrian signal units into conformance with current standards.	10	Intersection Related = 1 or 2

Roadside Obstacles and Barriers

Work Code	**Description**	**Definition**	**Reduction Factor %**	**Preventable Accident**
201	Install Median Barrier	Construct a metal or concrete median barrier where none existed previously.	65	(Vehicle Movements/Manner of Collision = 30) OR [(Point of Impact = 4, 5, or 63) AND (Object Struck + 1, 3, 20-23, 29-30, 32-36, 39-40, 42, 56, 60, 62, or 63)]
202	Convert Median Barrier	Remove an existing metal median barrier system and install a concrete median barrier.	40	[(Point of Impact = 4, 5, 12, 16, or 63) AND (Object Struck = 23, 39, 56, 62, or 63)] OR (Vehicle Movements/Manner of Collision = 30)
203	Install Raised Median	Install a roadway divider using barrier curb.	25	(Part of Roadway No. 1 Involved = 1) AND (Vehicle Movements/Manner of Collision = 10, 14, 20-22, 24, 26, 28-30, 34, OR 38)
204	Flatten Side Slope	Provide an embankment side slope of 6:1 or flatter.	46	Roadway Related = 3
205	Modernize Bridge Rail and Approach Guardrail	Improve existing substandard bridge rail and approach guardrail to current design standards. Post spacing, end treatment, and length of need should be considered. For length of need, if the existing length is less than 20% of the current design length, use W.C.	15	(Object Struck = 23, 39-41 or 56) OR (Bridge Detail = 2 or 3)

206	Improve Guardrail to Design Standards	Bring existing substandard guardrail into conformance with current design standards.	7	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
207	Install Protection	Provide guardrail or concrete traffic barrier where none existed previously. Refer to W.C. 206 for improving existing guardrail and W.C. 208 for the installation of protection at bridge ends.	30	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
208	Install Protection at Bridge Ends	Provide guardrail, concrete traffic barrier, or other protective system at bridge ends where no protection existed previously. Refer to W.C. 207 for installation of new guardrail and W.C. 206 for improving existing guardrail.	50	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
209	Safety Treat Fixed Objects	Remove, relocate or of safety treat all fixed objects within the project limits, to include both point and continuous objects. Refer to W.C. 210, 211, 212, 213, 214, 215, 216, 217, or 218 if the project includes only one type of fixed object. Guardrail should be coded separately.	55	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
210	Safety Treat Sign Support	Replace existing sign supports with breakaway supports. Refer to W.C. 217 for the installation of attenuation systems.	45	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
211	Safety Treat Luminaire Supports	Replace existing luminaire supports with breakaway supports.	35	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
212	Safety Treat Drainage Structures	Provide safety end treatments to crossroad and/or parallel drainage structures.	60	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
213	Widen Drainage Structures to Clear Zone	Widen existing structures to provide the desirable clear zone.	30	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
214	Remove Signal Supports	Redesign signals to remove the existing supports from the median.	10	(Point of Impact = 4, 5, 12, 16, or 63) AND (Object Struck = 20-26, 29-36, 40-42, 56-57, 60, 62, or 63)
215	Remove Trees (4:1 or 3:1 w/recovery)	Remove trees from the clear zone. Consideration is given to the embankment slope rate and the clear recovery area gained after removal.	10	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
216	Remove Trees (6:1)	Remove trees from the clear zone. Consideration is given to the embankment slope rate and the clear recovery area gained after removal.	50	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42)
217	Install Impact Attenuation System	Provide any of a variety of impact attenuators where none existed previously	60	(Object Struck = 20, 30, 40, or 42)
218	Widen Bridge	Provide additional width across an existing structure, either by rehabilitation or replacement. Specify existing bridge width, existing approach roadway width and roadway type (2 lane, 4 lane undivided, etc.)	55	(Bridge Number is not blank) OR (Bridge Detail is not blank) OR (Vehicle Movements/Manner of Collision = 20, 21, or 30) OR (Roadway Related = 2 or 3)
219	Install Curb-Control of Access	Install curb for an urban low speed design highway where no previous curb existed and the accident	10	[(Intersection Related = 3 or 4) AND (Vehicle Movements/Manner of

		history indicates a control of access problem.		Collision = 10-19, 20-29, 33-39, or 40-44)] OR (Roadway Related = 2 or 3) IR (Object Struck = 20, 22-23, 26, or 29-36) OR (First Harmful Event = 1 or 4)
220	Relocate Luminaire Supports From Median	Relocate luminaire supports from median (usually narrow) and place between outside curb and R.O.W. Refer to Work Code 211 for safety treating luminaire supports.	To be defined.	(Roadway Related = 2 or 3) OR (Object Struck = 20-26, 29-36, 40-42, 56-58, 60, 62, or 63)
221	Remove or Modify Barrier Curb	Remove or make traversable the barrier curb in front of existing guardrail or concrete traffic barrier.	30	(Object Struck = 21, 23, 39, 41, or 56) OR (Vehicle Movement/Manner of Collision = 30)
222	Improve Impact Attenuation System	Improve existing impact attenuators.	10	(Object Struck = 20,30,40 or 42)

Resurfacing and Roadway Lighting

Work Code	Description	Definition	Reduction Factor %	Preventable Accident
301	Resurfacing with Milepoints	Provide a new roadway surface to increase pavement skid numbers on the lane(s) in the direction of travel of the milepoints.	42	(Surface Condition = 2) AND [(Direction of Travel 1 = 1) OR (Direction of Travel 2 = 1)]
302	Resurfacing opposite Milepoints	Provide a new roadway surface to increase payment skid numbers on the lane(s) in the direction of travel opposite the milepoints.	42	(Surface Condition = 2) AND [(Direction of Travel 1 = 5) OR (Direction of Travel 2 = 5)]
303	Resurfacing	Provide a new roadway surface to increase pavement skid numbers on all the lanes.	42	Surface Condition = 2
304	Safety Lighting	Provide roadway lighting, either partial or continuous, where either none existed previously or major improvements are being made. Refer to W.C. 305 for intersection lighting.	25	Light Condition = 3 or 4
305	Safety Lighting at Intersection	Install lighting at an intersection	75	Light Condition = 3 or 4

Pavement Markings

Work Code	Description	Definition	Reduction Factor %	Preventable Accident
401	Install Pavement Markings	Place complete pavement markings, excluding crosswalks, in accordance with the TMUTCD where either no markings or nonstandard markings exist. Refer to W.C. 402 for edge marking, W.C. 403 for pedestrian crosswalks, W.C. 404 for centerline striping.	20	(Road Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 21 or 30) OR (First Harmful Event = 3)
402	Install Edge Marking	Place edge lines where none existed previously.	25	Roadway Related = 2 or 3
403	Install Pedestrian Crosswalk	Place pedestrian crosswalk markings where none existed previously. Refer to W.C. 114 for school zones, and W.C. 110 for pedestrian signal.	10	First Harmful Event = 1
404	Install Centerline Striping	Provide centerline striping where either no markings or nonstandard markings existed previously. Refer to W.C. 401 for complete pavement markings.	65	Vehicle Movements/Manner of Collision = 30

405	Install Traffic Buttons	Placed raised nonreflectorized traffic buttons for improved visibility in daylight wet surface conditions. Buttons will be installed where no buttons existed previously. Refer to W.C. 406 for installation of traffic buttons.	30	[(Surface Condition = 2) AND (Light Condition = 1)] OR (Vehicle Movements/Manner of Collision = 21 or 30)
406	Install Raised Reflective Pavement Markers	Place raised reflective pavement markers for improved visibility at night and in wet surface conditions. Markers will be installed where none - existed previously. Refer to W.C. 405 for installation of traffic buttons.	25	(Surface Condition = 2) or (Light Condition = 3 or 4)
407	Install Sidewalks		20	First Harmful Event = 1 or 5
408	Install Bike Lane		20	First Harmful Event = 5

Roadway Work

Work Code	Description	Definition	Reduction Factor %	Preventable Accident
501	Modernize Facility to Design Standards	Provide modernization to all features within the right-of -way to achieve current desirable standards. This includes work such as widening the travelway, widening the shoulders, constructing shoulders, flattening the side slopes, and treating roadside obstacles.	15	All
502	Widen Lane(s)	Provide additional width to the lanes(s). Refer to W.C. 517 if adding a through lane.	30	(Roadway Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 12, 21, 23, 30, or 33)
503	Widen Paved Shoulder	Extend the existing paved shoulder to achieve desirable shoulder width. Refer to W.C. 504 for constructing a paved shoulder.	12	(Roadway Related = 2 or 3) OR (First Harmful Event = 4)
504	Construct Paved Shoulders	Provide paved shoulders to desirable width where no shoulders existed previously. Refer to W.C. 503 for widening paved shoulders.	15	(Roadway Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 20, 23-24, or 30) OR (First Harmful Event = 4)
505	Improve Vertical	Reconstruct the roadway to improve sight distance.	50	(Roadway Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 20-24, 30, 32, or 34)
506	Improve Horizontal Alignment	Flatten existing curves. Refer to W.C. 507 for providing superelevation, and W.C. 508 for intersection realignment.	50	(Roadway Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 20-24, or 30)

507	Increase Superelevation	Provide increased superelevation on an existing curve.	65	(Roadway Related = 2 or 3) OR (Vehicle Movements/Manner of Collision = 30)
508	Realign Intersection	Improve an existing intersection by partial or complete relocation of the roadway(s). Refer to W.C. 509 for channelization, and W.C. 506 for improving horizontal alignments.	To be defined.	Will be determined from supplied diagram
509	Channelization	Install islands and/or pavement markings to control or prohibit vehicular movements. A sketch of the proposed channelization should be provided. Refer to W.C. 508 for intersection realignment.	To be defined.	Will be determined from supplied diagram
510	Construct Turnarounds	Provide turnarounds at an intersection where none existed previously.	40	(Intersection Related = 1 or 2) AND (Vehicle Movements/Manner of Collision = 12, 14, 18, 20, 22, 24, 26, 28, 29, or 34)
511	Add Acceleration/Deceleration Lanes	Construct acceleration and/or deceleration lanes where none existed previously.	10	[Outside 2 Lanes (Main) AND (Vehicle Movements/Manner of Collision = 20 or 21)]
512	Entrance Ramp Modification	Reconstruct existing ramps to conform to current desirable standards.	30	[(Part of Roadway Involved = 2) AND (Vehicle Movements/Manner of Collision = 20)] OR [All Accidents on Outside 2 Main Lanes from 1/10 Mile Before Connection to 2/10 Mile After Connection]

513	Exit Ramp Modification	Reconstruct existing ramps to conform to current desirable standards.	20	[(Part of Roadway Involved = 2 or 4) AND (Roadway Related = 2 or 3)] OR [(Part of Roadway Involved = 2 or 4) AND (Vehicle Movements/Manner of Collision = 10-39)]
514	Grade Separation	Construct vertical separation of intersecting roadways.	80	All
515	Construct Interchange	Construct vertical separation of intersecting roadways to include interconnecting ramps.	55	All
516	Close Crossover	Permanently close an existing crossover.	95	(Part of Roadway Involved = 1) AND (Vehicle Movements/Manner of Collision = 10, 14, 20-22, 24, 26, 28-30, 34, or 38)
517	Add Through Lane	Provide an additional travel lane.	28	Vehicle Movements/Manner of Collision = 20-24, 26-27, or 29-30
518	Install Continuous Turn Lane	Provide a continuous two-way left turn lane where none existed previously.	40	Vehicle Movements/Manner of Collision = 20-24, 26-27, 29-30, 34, or 38
519	Add Left Turn Lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified.	25	Vehicle Movements/Manner of Collision = 20-24, 26-27, 29-30, 34, or 38
520	Lengthen Left Turn Lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified.	40	Vehicle Movements/Manner of Collision = 20-22
521	Add Right Turn Lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified.	25	Vehicle Movements/Manner of Collision = 20-23, 25-27, 33, or 36.
522	Lengthen Right Turn Lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified.	40	Vehicle Movements/Manner of Collision = 20-22
523	Construct Pedestrian Over/Under Pass	Construct a pedestrian crossover where none existed previously.	95	First Harmful Event = 1
524	Increase Turning Radius	Provide an increased turning radius at an existing intersection.	10	[(Vehicle. 1 Type = 2-3, or 5-8) AND (First Harmful Event = 7)] OR [(Vehicle No. 2 Type = 2-3, or 5-8) AND (First Harmful Event = 7)] OR (Vehicle Movements/Manner of Collision = 13, 20-21, 30, or 33)

525	Covert to One-Way Frontage Roads	Convert two-way frontage roads to one-way operation.	25	
526	Increase Vertical Clearance (Lower Grade)	Increase vertical clearance of a roadway underneath an overhead obstacle by lowering the roadway grade.	50	Object Struck = 43
527	Increase Vertical Clearance (Remove Structure)	Remove an overhead structure in order to increase vertical clearance.	95	Object Struck = 43
528	Construct Median Crossover	Provide crossovers in the median where none previously existed.	20	(Part of Roadway Involved = 1) AND (Vehicle Movement/Manner of Collision = 10, 14, 20-22, 24, 26, 28, 29, 34, or 38)
529	Remove Raised Median/Concrete Island	Permanently remove raised median/concrete island.	35	Object Struck = 21 or 36
531	Install Jiggle Bar Tiles as a Shoulder Treatment.	Install jiggle bar tiles on the shoulder as a shoulder texturing treatment.	25	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 30)
532	Texturize Shoulders (rolled in or milled in)	Install milled-in or rolled-in rumble strips along the shoulder.	25	(Roadway Related = 2 or 3) OR (Vehicle Movement = 30)
533	Texturize Shoulders (Profile Pavement Markers)	Install high-profile pavement markers along the shoulder.	15	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 30) OR (Surface Condition = 2)
534	Texturize Shoulders (Traffic Buttons)	Install traffic buttons along the shoulder.	10	(Roadway Related 2 or 3) OR (Vehicle Movement/Manner of Collision = 30) OR (Surface Condition = 2)
535	Widen Median Opening for Storage	Widen an existing opening in the median to accommodate vehicles for storage.	20	Vehicle Movement/Manner of Collision = 10,14,20, or 21
536	Widen Paved Shoulders (to >5 ft.)	Extend the existing paved shoulder to greater than 5 ft. Refer to W.C. 504 or 537 for constructing a paved shoulder.	40	(Roadway Related = 2 or 3) OR (First Harmful Event = 4)
537	Construct Paved Shoulders (to >5 ft.)	Provide paved shoulders 5 feel or greater where no shoulders existed previously. Refer to W.C. 503 or 536 for widening paved shoulders.	40	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 20,23-24, or 30) OR (First Harmful Event =4)
538	Convert 2 Lane Facility to 4 Lane Divided	Convert an existing 2 lane facility to a 4 lane divided facility.	45	(Roadway Related = 2 or 3) OR (Vehicle Movement/Manner of Collision = 10, 13, 14, 20, 21, 22, 24, or 30)
539	Install Grass Median on Undivided Facility	Install a grass median on an undivided facility.	40	Vehicle Movements/Manner of Collision = 30

Additional Work Codes

Work Code	Description	Definition	Reduction Factor %	Preventable Accident

132	Install Advanced Warning Signals and Signs	Provide flasher units and signs in advance of hazard where none previously existed.	10	To be determined
133	Improve School Zone	Improve an existing school zone by upgrading signing, pavement markings, or signals.	5	All

APPENDIX D

HAZARD ELIMINATION PROGRAM (HES): SERVICE LIVES

Hazard Elimination Program (HES)
Service Lives

Intersection and Traffic Control
HES Service Lives

Project	**Projected Service Life (Years)**
Construct Turning Lanes (includes two-way continuous turn lanes)	10
Provide Traffic Channelizations	10
Improve Sight Distance	10
Install Traffic Signs	6
Install Pavements Markings	2
Install Delineators	2
Install Illumination	15
Upgrade or Install Traffic Signals	10
Install Flashing Beacons	10

Structures
HES Service Lives

Project	**Projected Service Life (Years)**
Widen or Modify Bridge for Safety	20
Replace Bridge for Safety	30
Construct New Bridge for Safety	30
Replace or Improve Minor Structure for Safety	20
Upgrade Bridge Rail	10
Construct Overpass or Interchange	30

Roadway and Roadside
HES Service Lives

Project	**Projected Service Life (Years)**
Widen Traveled-Way (no lanes added)	20
Add Lane(s) to Traveled-Way	20
Construct Median for Traffic Separation	20

Widen or Improve Shoulder	20
Realign Roadway (except at railroads)	10
Overlay for Skid Treatment	10
Groove Pavement for Skid Treatment	10
Install Breakaway Sign Supports	10
Install Guardrail End Treatments	10
Upgrade Guardrail	10
Upgrade Median Barrier	15
Install New Median Barrier	15
Install Impact Attenuators	10
Flatten or Regrade Side Slopes	20
Install Bridge Approach Guardrail Transitions	10
Remove Obstacles	20
Safety Treat Drainage Structures	20
Increase Superelevation	10
Add Acceleration/Deceleration Lane(s)	20
Close Crossover	20

Note: The projected service lives for various HES projects provided in this appendix were adapted from the FHWA "1993 Annual Report on Highway Safety Improvement Programs."

APPENDIX E

VISUAL BASIC (VB) CODE FOR FUNCTION "SUMMATION"

```
//**Start of Code**//

Public Function Summation(S As Variant, Q As Variant, L As Variant, y As Variant)

Dim B_incriment As Variant
B_incriment = 0

For i = 2 To L
B_incriment = ((S + Q / 2) + ((i - 1) * Q)) / ((1 + y) ^ i)
Summation = Summation + B_incriment
Next i

Summation = Summation + (S + Q / 2) / (1 + y)

End Function

//**End of Code**//
```

APPENDIX F

PROJECT NUMBERS AND UNIQUE ID'S

Program Year: 1998

No	Unique ID
1	1998 01005S
2	1998 01006S
3	1998 01008S
4	1998 02004S
5	1998 02006S
6	1998 02009S
7	1998 05001S
8	1998 05002S
9	1998 11011S
10	1998 14003S
11	1998 14004S
12	1998 14010S
13	1998 14012S
14	1998 14013S
15	1998 14014S
16	1998 15007S
17	1998 17006S
18	1998 17008S
19	1998 18030S
20	1998 12001S
21	1998 19013S
22	1998 19009S
23	1998 19010S
24	1998 11008S
25	1998 11007S
26	1998 01004S
27	1998 11013S
28	1998 09002S
29	1998 02007S
30	1998 02003S
31	1998 18031S
32	1998 08003S

Program Year: 1996

No	Unique ID
1	1996 21008S
2	1996 19001S
3	1996 19003S
4	1996 19004S
5	1996 21008S
6	1996 17004S
7	1996 10007S
8	1996 11004S
9	1996 11006S
10	1996 22014S
11	1996 23002S
12	1996 23003S
13	1996 01003S
14	1996 01004S
15	1996 01005S
16	1996 01007S
17	1996 01009S
18	1996 01011S
19	1996 01012S
20	1996 08002S
21	1996 10003S
22	1996 14002S
23	1996 14009S
24	1996 15001S
25	1996 17003S
26	1996 18008S
27	1996 01001S
28	1996 21014S
29	1996 10001S
30	1996 22003S
31	1996 22002S
32	1996 01010S
33	1996 12005S
34	1996 12004S
35	1996 18005S
36	1996 11001S
37	1996 10001S
38	1996 18001S
39	1996 18003S
40	1996 23004S

Program Year: 1995

No	Unique ID
1	1995 19002S
2	1995 19003S
3	1995 19004S
4	1995 23009S
5	1995 24001S
6	1995 24002S
7	1995 15003S
8	1995 15004S
9	1995 15005S
10	1995 15007S
11	1995 16004S
12	1995 18001S
13	1995 18003S
14	1995 01005S
15	1995 03001S
16	1995 06010Y
17	1995 10004S
18	1995 10005S
19	1995 11001S
20	1995 11002S
21	1995 11005S
22	1995 11011S
23	1995 12003S
24	1995 12006S
25	1995 12007S
26	1995 12009S
27	1995 12010S
28	1995 14007S
29	1995 10003S
30	1995 11009S
31	1995 14001S
32	1995 15001S
33	1995 18004S
34	1995 21001S
35	1995 11008S
36	1995 11006S
37	1995 16001S
38	1995 01004S
39	1995 01007S
40	1995 08003S
41	1995 14003S

Program Year: 1994

No	Unique ID
1	1994 01005X
2	1994 03001X
3	1994 06001Y
4	1994 11002S
5	1994 11005S
6	1994 12001S
7	1994 14001X
8	1994 14002X
9	1994 14003X
10	1994 14007X
11	1994 17001X
12	1994 17002X
13	1994 17004X
14	1994 17006X
15	1994 17007X
16	1994 21007X
17	1994 23009X
18	1994 23010X
19	1994 23012X
20	1994 24001S
21	199424003Y
22	199424004Y
23	199401004X
24	199405001X
25	199412003X
26	199423002X
27	1994 01002X
28	1994 16002Y
29	1994 23013X
30	199411013X
31	199411009X
32	199412002X
33	1994 23011X
34	1994 10002X
35	1994 21005Y
36	1994 03002X
37	1994 23013X
38	1994 12004X

Program Year: 1992

No	Unique ID	No	Unique ID
1	1992 06009Y	41	9217003X
2	1992 08001S	42	9218004X
3	1992 09001S	43	9218005X
4	1992 12009X	44	9223002X
5	1992 14009X	45	199206004X
6	1992 14012S	46	1992 11001S
7	1992 16003Y	47	9206006X
8	1992 16004Y	48	199221011X
9	1992 17009S	49	199210002S
10	1992 19001S	50	1992 06010Y
11	1992 21018X	51	1992 06008Y
12	1992 14011S	52	199212001X
13	199216002Y	53	9212005X
14	199216005Y	54	1992 16001S
15	199214013Y	55	9201002X
16	199218003X	56	199210001S
17	199221003X	57	1992 21020X
18	199224001S	58	1992 21025Y
19	199215001X	59	199221002X
20	199215004X	60	199221005X
21	199215006X	61	199221012X
22	199215007X	62	199221013X
23	199211007S	63	199221015X
24	199211009S	64	199221006X
25	199214001X	65	199214001S
26	199214002X	66	1992 21024Y
27	199214003X	67	1992 21026Y
28	199214006X	68	9217001X
29	199214007X	69	9217002X
30	199224002S	70	1992 21022X
31	9201007X	71	1992 21023S
32	9206001X	72	199221004X
33	9206002X	73	199221014X
34	9206005X	74	9221019X
35	9206007X	75	1992 01005X
36	9211004S	76	1992 01006X
37	9211005S	77	199201001X
38	9215009X	78	1992 07002S
39	9215010X	79	1992 11001S
40	9215011X		

VITA

Name: Giridhar Reddy Singi Reddy

Address: H. No – 11/1/333/a, Secunderabad, Andhra Pradesh, India - 061

Email: giridhar3183@gmail.com

Education: Bachelor of Engineering, Osmania University, India (August 2005)
Master of Science, Texas A&M University (December 2007)